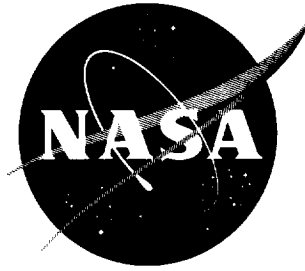


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EXPLORATORY ENVIRONMENTAL TESTS OF SEVERAL HEAT SHIELDS

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TECHNICAL NOTE D-897

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SUMMARY

Exploratory tests have been conducted with several conceptual radiative heat shields of composite construction. Measured transient temperature distributions were obtained for a graphite heat shield without insulation and with three types of insulating materials, and for a metal multipost heat shield, at surface temperatures of approximately 2,000° F and 1,450° F, respectively, by use of a radiant-heat facility. The graphite configurations suffered loss of surface material under repeated irradiation. Temperature distribution calculated for the metal heat shield by a numerical procedure was in good agreement with measured data.

Environmental survival tests of the graphite heat shield without insulation, an insulated multipost heat shield, and a stainless-steel-tile heat shield were made at temperatures of 2,000° F and dynamic pressures of approximately 6,000 lb/sq ft, provided by an ethylene-heated jet operating at a Mach number of 2.0 and sea-level conditions. The graphite heat shield survived the simulated aerodynamic heating and pressure loading. A problem area exists in the design and materials for heat-resistant fasteners between the graphite shield and the base structure. The insulated multipost heat shield was found to be superior to the stainless-steel-tile heat shield in retarding heat flow. Overlapped face-plate joints and surface smoothness of the insulated multipost heat shield were not adversely affected by the test environment.

The graphite heat shield without insulation survived tests made in the acoustic environment of a large air jet. This acoustic environment is random in frequency and has an overall noise level of 160 decibels.

INTRODUCTION

Some basic approaches to the design of heat-resistant structures for application to high-speed vehicles subject to aerodynamic heating are unprotected structures made of high-temperature materials which are capable of radiating part of the heat input, protected structures employing transpiration cooling or an external layer of ablative material which absorbs heat as it is consumed, heat sink depending on mass

of material to provide adequate heat capacity, and insulated structures in which the load-carrying members are kept cool by insulation held in place by an outer radiative heat shield. These design approaches are discussed more fully in reference 1. The insulated-structure approach is investigated in references 2 and 3.

The present paper presents data obtained from exploratory tests of several conceptual radiative heat shields in the category of the insulated-structure approach. Radiative heat shields of three types of construction are considered. The outer surface of these heat shields dissipates part of the heat input. The remainder of heat flowing through the heat shield may be partially blocked by bulk insulation and reflective foils. Small conduction areas in the heat-shield supporting material and fastening devices assist in retarding heat flow. These methods of retarding heat flow have been incorporated in the heat shields considered. Provisions have been made to permit relative expansion of the heat shields and underlying primary structure by use of oversize holes. The heat-shield constructional concepts investigated are a graphite heat shield in thin-flat-plate form, attached with ceramic fasteners to a metal base plate representing the primary structure; a metallic sandwich-type heat shield employing multipost construction; and thin-gage metal tiles attached to the primary structure with rigidly fastened flexible strip supports.

Unconventional structural configurations and material applications in these heat-shield assemblies have prompted exploratory investigation. A radiant-heat facility at the Langley Research Center was used to obtain temperature distributions for a graphite heat shield without insulation and with three types of insulating material, and for a metallic sandwich-type heat shield of multipost construction, at surface temperatures of approximately 2,000° F and 1,450° F, respectively. Simulated environmental survival tests of a graphite heat shield without insulation, an insulated multipost heat shield, and a metal-tile heat shield were made, at approximately 2,000° F, in the ethylene-heated high-temperature jet located at the NASA Wallops Station. The tests were conducted at a Mach number of 2.0 and a stagnation temperature of 3,000° F. Exploratory acoustic tests of a basic graphite heat shield were conducted in an acoustic environment of a large air jet at the Langley Research Center. This acoustic environment is random in frequency and has an overall noise level of 160 decibels.

DESCRIPTION OF TEST PANELS

Graphite Heat Shield

The basic graphite heat shield is machined from grade AGR graphite into thin-flat-plate form 6- by 6-inches square. Figures 1(a) and 1(b)

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are dimensional sketches of the basic graphite heat shield. Integral bosses are provided at each corner and at the center to serve as supports. The boss-type supports provide space for insulation between the flat surface of the graphite and a 1/8-inch-thick base plate of SAE 1020 steel representing the primary structure. The thin-flat-plate heat shield is attached to the base plate at the corners of the 6- by 6-inch square through oversize holes in the boss-type supports. Allowance for thermal expansion is made by use of the oversize holes. The flat-plate portion of the configuration is 0.20 inch thick for all panels fabricated except one. For this one the flat-plate portion is made of 0.30-inch-thick graphite to provide a survival test panel in the event of strength failure of the thinner test panel. Grade AGX graphite was used for this panel because grade AGR was not available. All graphite surfaces have a smooth machine finish. Molded zirconium dioxide fasteners were used to minimize heat flow to the base plate and to obtain large contact area with the brittle graphite. Conventional steel bolts were used with the zirconium dioxide fasteners as illustrated in figure 1(b). The heat shield of 0.20-inch-thick graphite weighs 2.34 lb/sq ft, not including the base plate. Oxidation-resistant surface coatings were not employed on any test panels. Typical thermocouple locations are shown in figure 1(c).

In addition to the basic graphite panel, three modified heat-shield configurations were obtained by installing various insulating materials in the air chamber of the basic graphite heat shield. Graphite test panels which have insulation in the space provided by boss-type supports also have insulation installed between the supports and the base plate. Insulation between the supports and the base plates consists of two 0.04-inch-thick layers of a fibrous ceramic material compressed to a total thickness of 0.04 of an inch. The three modified heat-shield configurations are as follows:

Bulk insulation.- A fibrous ceramic material was used for the bulk insulation. The approximate density of the insulation is 12.0 lb/cu ft; total weight of the assembly is 2.81 lb/sq ft, not including the base plate. Figure 1(c) is a sketch of the basic graphite heat shield with bulk insulation.

Radiation shields.- The radiation shield consists of two 0.001-inch-thick gold sheets formed into 3/32-inch-high corrugated sheets placed in the air chamber with corrugations horizontal and mutually perpendicular. The total weight of the assembly is 2.65 lb/sq ft, not including the base plate. Figure 1(d) is a sketch of the basic graphite heat shield with radiation shields.

Composite blanket.- The composite blanket consists of one 0.001-inch-thick sheet of gold sandwiched between two 1/32-inch-thick layers of fibrous glass compressed in felt form. The total weight of the assembly

is 2.47 lb/sq ft, not including the base plate. Figure 1(e) is a sketch of the basic graphite heat shield with the composite-blanket insulation.

Multipost Heat Shield

Figure 2 is a schematic representation of the multipost heat shield. The heat shield consists of a face plate and supporting posts in a 1/4- by 1/4-inch-square array. The heat shield is mounted on a sandwich-type structure, which represents the basic structure and is made of two face plates with a corrugated sheet as core material. The entire assembly is made of AISI stainless steels and is resistance welded.

All face plates and the corrugated sheet are made of 347 stainless steel and are 0.011 inch thick. The posts are made of 310 stainless-steel wire and are 0.035 inch in diameter. Nominal size of the test panel is 3/4 by 6 by 6 inches. The multipost heat shield, consisting of posts and a face plate supported by them weighs 0.7 lb/sq ft.

Surface roughness of the face plate of the heat shield, due to resistance welding, is 0.031 inch as indicated by the difference in highest and lowest points on the surface. Thermocouple locations are shown in figure 3.

Insulated Multipost Heat Shield

A photograph, dimensional cross section, and thermocouple locations of the insulated multipost heat shield are shown in figure 4. The heat shield consists of four 6- by 6-inch panels of multipost construction, fasteners for attachment to the basic structure, and insulating material. The fasteners are welded to the multipost panels and extend through over-size holes in the basic structure which is represented by the sandwich-type panel of corrugated construction. Five fasteners per 6- by 6-inch panel are used, one at each corner and one in the center. Conventional steel nuts hold the heat shield in place. Adjacent edges of the face plates of the multipost heat shield are overlapped to allow for thermal expansion.

The face plates of the insulated multipost construction are 0.0075-inch-thick 302 stainless steel. The posts are 0.035 inch in diameter and are made of 310 stainless steel. The corrugated panel is made of 0.011-inch-thick 347 stainless steel as shown in figure 4, and the fasteners are made of the same material. Insulation between the multipost heat shield and the corrugated panel is 1/4 inch thick, 12- by 12-inch Min-K 1301. The insulated multipost heat shield weighs 1.4 lb/sq ft, excluding the basic structure. Surface roughness after

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fabrication as indicated by the maximum difference in high and low points on the surface was 0.028 inch.

Stainless-Steel-Tile Heat Shield

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A dimensional cross section and thermocouple locations of the stainless-steel-tile heat shield are shown in figure 5. More details of the heat shield are shown in a subsequent photograph. The heat shield consists of 0.015-inch-thick, 2- by 2-inch tiles of 321 stainless steel and 0.020-inch-thick, 3/8-inch-wide support strips of the same material. Ceramic-fiber insulation in felt form, 1/16 inch thick, prevents contact of the tiles with the support strips and contact of the support strips with the base plate. Steel rivets are used throughout for fastening. The heat shield, excluding the base plate, weighs 1.3 lb/sq ft.

DESCRIPTION OF TESTS

Radiant-Heater Tests

A radiant-heat facility at the Langley Research Center was employed to obtain measured temperature distributions of the graphite heat shields and the multipost heat shield. This facility consists of two bus bars with a single bank of 3/8-inch-diameter quartz lamps supported between them by lead wires. The bus bars are slotted for 3/4-inch uniform spacing of the lamps. Figure 6 is a schematic sketch of a test setup indicating the arrangement of lamps and bus bars. The test facility has provisions for programming the specimen temperature as a function of time. More detailed information on quartz-lamp radiant heaters may be found in reference 4.

Graphite heat shield.- Measured temperature-time histories were obtained for four graphite heat-shield assemblies previously described as basic graphite heat shield, graphite heat shield with bulk insulation, graphite heat shield with radiation shield, and graphite heat shield with composite blanket. The four assemblies were individually mounted in support frames and irradiated simultaneously. The panels were located 2 inches from the face of the lamps and each exposed surface was parallel to the bank of lamps in order to obtain equal incident radiant heat flow for all panels. A control thermocouple was installed in the basic graphite panel (without insulation) for programming temperature-time histories. The temperature rise was programmed for a rate of 40° F/sec, at the control thermocouple location, from room temperature to levels of 600° F, 1,200° F, and 1,800° F. At levels of 600° F, 1,200° F, and 1,800° F the temperatures of the irradiated face plate were held approximately constant until the temperature

of the base plate reached a near equilibrium condition. Irradiation of the panels under the same plan was repeated for a temperature rise at the rate of 80°F/sec , making a total of six exposures for each panel.

Chromel-alumel thermocouples were used. The bimetallic thermocouple wires were formed into weldment beads and lightly pressed into holes drilled in the graphite. Thermocouples numbers 1 and 2 for all panels were installed at a depth of 0.05 inch from the irradiated surface and the back surface, respectively. Thermocouple number 3 was resistance welded to the interior surface of the steel base plate. Thermocouple number 4 was resistance welded to the exterior surface of the base plate, in the area below a boss-type support.

Multipost heat shield.- The face plate supported by multipost construction was exposed to radiant heat flux corresponding to surface temperature rises of 20°F/sec for one test and 170°F/sec for a second test. The edges of the multipost heat-shield assembly were covered with U-channels to support the heat shield and prevent outside air from flowing through the assembly during tests. Chromel-alumel thermocouples were installed by resistance welding. The thermocouples were located near the center of area of the 6- by 6-inch panel to minimize edge effects. Five thermocouples were used to measure the temperature distribution and for convenience were numbered 1, 5, 11, 20, and 25 as shown in figure 3. The thermocouples are referred to in this paper in regard to a numerical method for calculating temperature distribution. A control thermocouple was located near thermocouple number 1 on the back surface of the irradiated face plate for programing the temperature-time history of the face plate.

Survival Tests

Survival tests were made in the ethylene-heated high-temperature jet located at the NASA Wallops Station. This facility is a blowdown-type jet with characteristic running conditions of a Mach number of 2.0, a dynamic pressure of 6,000 lb/sq ft, and a stagnation temperature of $3,000^{\circ}\text{F}$. Jet stream temperature may be varied up to $3,300^{\circ}\text{F}$ by controlling the quantity of ethylene fuel introduced in the jet stream. Motion pictures at 3,000 frames per second were taken during each test. A detailed description of this facility is contained in reference 5.

Basic graphite heat shield.- Survival tests were made for the basic graphite panel without insulation. Panels were mounted flush with the surface of a wedge-shaped support stand.

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Figure 7 shows the setup of a typical ethylene-jet survival test. A thermal expansion gap of 0.03 inch was provided between the edges of the graphite panel and the support stand. Instrumentation consisted of two thermocouples in proximity installed in the thin flat-plate portion of the basic graphite panel, 0.05 inch below the graphite surface. The survival tests are summarized in table I.

Insulated multipost heat shield.- The insulated multipost heat shield was mounted for a survival test in the same manner as that shown in figure 7. The support stand and test assembly were fixed at an angle of attack of 30° , leading edge down, with respect to the jet center line. Temperature distribution through the overall thickness of the assembly was measured by chromel-alumel thermocouples, resistance welded to the face plates. The ethylene-jet test conditions for a duration of 45 seconds are given in table I.

Stainless-steel-tile heat shield.- The stainless-steel-tile heat shield was mounted in a wedge-shaped support stand and held in place by retaining flanges fastened to the support stand. The support stand and assembled tile surface were inclined at an angle of attack of 50° for this test. Temperature distribution through the overall thickness of the test panel was measured by chromel-alumel thermocouples resistance welded to the test panel at three locations. Ethylene-jet test conditions during the test run of 40 seconds are given in table I.

Acoustic Test

A large air jet at the Langley Research Center was employed as a noise generator to conduct acoustic tests of the basic graphite heat shield without insulation. The jet exit is circular in cross section and has a 12-inch diameter. The test area is located just downstream of the jet exit and around the periphery of the jet exhaust. Noise levels of approximately 160 decibels are generated in this area. More information on this facility is given in reference 6.

Exposure of a basic graphite panel, with 0.20-inch-thick flat-plate section, to an intense acoustic environment was made at two positions in the vicinity of the jet exit as is shown in figure 8. Tests were made consecutively at positions A and B. The graphite panel was rigidly attached to an aluminum plate and mounted on supporting structural framework near the jet exit. Air impingement was not experienced by the panel since in each test position the panel was mounted outside the jet stream approximately parallel to the stream divergent boundaries. A diaphragm crystal-type microphone was used for measuring the noise environments at the two test-panel positions prior to the tests. The measured signals

were fed into a sound-level meter and octave-band analyzer to obtain the noise spectrum at each panel position. Noise spectra are presented in figure 9.

RESULTS AND DISCUSSION

Radiant-Heater Tests

Graphite heat shields.- Measured temperature-time histories of the four graphite heat-shield configurations tested at a rate of temperature rise of approximately 40° F/sec to a maximum face-plate temperature of $1,800^{\circ}$ F are shown in figures 10 to 13. The figures give data only for the first 2 minutes of test time. Measured data for all tests are tabulated in tables II and III.

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Comparison of figures 10 to 13 shows that the insulating materials were nearly equally effective in producing significant reductions in temperatures through the shields. The rate of temperature rise indicated by thermocouple number 1 on each of the four panels tested is approximately the same, and, the maximum temperatures of the exposed graphite plates are within 200° F. As indicated by thermocouple number 3 on each of the modified panels, very little difference is noted in the insulating value of the modified panels.

Photographs of the four graphite heat-shield configurations after each had six exposures to radiant heat flow are shown in figures 14 to 17. Total exposure time for six exposures of each heat shield was 1 hour and 47 minutes of which approximately 59 minutes were at a temperature greater than $1,200^{\circ}$ F. The thickness of the graphite plate was 0.20 inch prior to tests. The graphite surface was initially flush with the top surface of ceramic fasteners. Loss of graphite material is noticeable in the photographs. Average thickness of the four panels after tests was 0.15 inch. Several of the ceramic fasteners showed slight evidence of fractures and spalling at the exposed surface.

Multipost heat shield.- Measured temperature-time histories for the multipost heat shield are shown in figure 18 for a face-plate temperature rise of approximately 20° F/sec. The maximum temperature of the irradiated face plate as indicated by thermocouple number 5 is approximately $1,400^{\circ}$ F at 68 seconds. Thermocouple number 26 indicates a temperature of approximately 230° F at 68 seconds. The temperature rise as indicated by thermocouple number 26 is increasing whereas that of thermocouple number 5 is essentially constant. Figure 19 shows measured temperature-time histories of the multipost heat shield for a temperature rise of approximately 170° F/sec, on the irradiated face plate. In comparison to the temperature rise of 20° F/sec, this type assembly would provide a relatively

short time of thermal protection at 170°F/sec input. Although the assembly with insulation was not tested in this facility, results of the aforementioned tests of the graphite heat shield indicate that insulation would have a marked effect on extending the protection period of multipost-type heat shields. Figure 20 is a photograph of the multipost heat shield after exposure to face-plate temperature rises of 20°F/sec and 170°F/sec . Surface distortion, as indicated by the difference in maximum and minimum measurements on the 6- by 6-inch exposed face plate, was 0.025 inch. This roughness is slightly less than that measured prior to tests.

L A calculated temperature distribution was made by the method described
1 in appendix A. The measured temperature rise of approximately 20°F/sec
5 at the location of thermocouple number 1 was employed in the calculation.
2 Variations of temperature with time at the locations of thermocouple num-
4 bers 5, 11, 20, and 26 were calculated and are shown in figure 18 for
comparison with measured data. Good agreement of calculated temperature
distribution with measured data was obtained. It appears that transient
temperature distributions through this type of complex structure can be
satisfactorily predicted, at least for the low rates of temperature rise
employed.

Survival Tests

Basic graphite heat shield.- Ethylene-jet test number 1 (table I) of the basic graphite heat shield with zirconium dioxide fasteners resulted in destruction of the heat shield. The motion pictures revealed spalling of the exposed surface of the two downstream zirconium dioxide fasteners eventuating in destruction of both fasteners. Flutter of the basic graphite panel was observed after loss of the fasteners for a period of 4.5 seconds prior to disintegration of the panel. Total test time from injection of the panel into the ethylene-jet stream to destruction was approximately 6.4 seconds.

Ethylene-jet test number 2 was a repeat of test number 1 with an identical basic graphite panel having the zirconium dioxide fasteners replaced with geometrically identical fasteners made of 347 stainless steel. This test was conducted in order to determine survival capabilities of the basic graphite panel per se. Inspection of the panel after ethylene-jet test number 2 revealed no visual damage other than a change in graphite surface texture which was probably due to oxidation. Maximum temperature of the flat-plate graphite as indicated by a chromel-alumel thermocouple was about $1,700^{\circ}\text{F}$, and the total test run time was 30 seconds.

Test numbers 3 and 4 at angles of attack of 3° and 8° , respectively, were satisfactory. Measured temperature-time histories are shown in figure 21 for the basic graphite panel with 0.20-inch-thick flat plate

at an angle of attack of 3° . Maximum temperature as indicated by the thermocouples is approximately $1,770^{\circ}$ F. The initial rate of temperature rise estimated from figure 21 is 200° F/sec. Surface pressure, estimated from two-dimensional wedge theory was 17.0 psia. Measured temperature-time histories are shown in figure 22 for the basic graphite panel having a 0.30-inch-thick flat plate at an angle of attack of 8° . Maximum temperature is approximately $1,675^{\circ}$ F. The initial rate of temperature rise estimated from figure 22 is 250° F/sec. The estimated surface pressure for an angle of attack of 8° was 22.0 psia.

It is noteworthy that the graphite structure tested survived the aerodynamic loading and heat flow of the ethylene jet. The present tests also show that a problem area exists on the fasteners and that more work is required in this area.

Insulated multipost heat shield.- Temperature-time histories at four thermocouple locations in the insulated multipost heat shield are shown in figure 23. The heat shield survived the high temperature rise indicated by thermocouple number 1. The apparent improvement in resistance to heat flow in this assembly appears to be due to the large amount of insulation between the heat shield and the corrugated panel.

Figure 24 is a photograph of the insulated multipost heat shield after ethylene-jet tests. Surface measurements on the exposed face plate after testing indicated a maximum difference of 0.069 inch between high and low points. The condition of the heat shield was generally good. Surface distortion and overlapped joints of the face plates were not adversely affected by the temperature and dynamic pressure. Surface pressure experienced by the insulated multipost heat shield at an angle of attack of 3° was calculated to be 17.0 psia.

Stainless-steel-tile heat shield.- Measured temperature-time histories for the stainless-steel-tile heat shield are shown by the data in figure 25. The maximum temperature of the tiles measured by thermocouple number 1 is $1,550^{\circ}$ F. Exposure of the stainless-steel-tile heat shield to the ethylene jet resulted in conditions shown by the photographs of figures 26 and 27.

Damage to the trailing-edge row of tiles may have been due to loss of confinement of the tile trailing edges by the retaining flange. Concavity and derangement of the tiles indicate inadequate strength and stiffness of the tiles for a temperature of $1,550^{\circ}$ F and a calculated surface pressure of approximately 19.0 psia at an angle of attack of 5° . Aerodynamic loads obtained in the ethylene-jet facility are severe as compared to loads experienced at high altitudes and Mach numbers. Flutter of individual 2- by 2-inch tiles was revealed by high-speed motion pictures of the tile heat shield during the ethylene-jet test.

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The insulated multipost heat shield, shown in figure 23, was found to be superior to the stainless-steel-tile heat shield in retarding heat flow to the base plate when tested in the ethylene jet.

Acoustic Test

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The noise environment for the acoustic tests is random in frequency and has an overall noise level of about 160 decibels. Detail noise-frequency spectra are shown in figure 9 for the two test positions. This figure shows that the overall sound pressure level in position B was 161 decibels whereas the overall sound pressure level of position A was 157 decibels. The panel was tested at position A for a period of 3 minutes and at position B for 6 minutes. Visual inspection of the graphite panel after tests revealed no structural damage.

CONCLUDING REMARKS

Exploratory tests have been conducted with several conceptual radiative heat shields of composite construction.

Radiant-heater tests of a graphite heat shield without insulation, with bulk insulation, with an insulating radiative shield, and with an insulating composite blanket shield showed that the insulating materials were nearly equally effective in producing significant reductions in temperatures through the shields. Radiant-heater tests of the graphite configurations showed that the shields lost surface material under repeated irradiation. The basic graphite heat shield survived the aerodynamic loadings of an ethylene-heated jet and the noise levels of an acoustic facility. The survival tests also showed that a problem area exists in the design and materials for the heat resistant fasteners between the graphite shield and base plate.

The insulated multipost heat shield was found to be superior to the stainless-steel-tile heat shield in retarding heat flow to the base plate when tested in the ethylene jet. Tiles of the latter shield fluttered and became distorted under the ethylene-jet loading and temperature conditions. Overlapped thin-face-plate joints and surface smoothness of the insulated multipost heat shield were not adversely affected by the test environment.

The calculated temperature distribution through the multipost heat shield was in good agreement with measured temperatures obtained from

radiant-heater tests. The numerical method used appears to be adequate for predicting the temperatures through complex structures, at least for low rates of heat input.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., April 27, 1961.

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APPENDIX A

METHOD OF CALCULATING TEMPERATURE DISTRIBUTION

The calculated transient temperature distribution shown in figure 18, for comparison with measured temperature-time histories, was calculated by a numerical method similar to the procedure of reference 7. The conducting body of reference 7 is divided into small geometrical shapes and a heat-balance equation is written for each shape. Solution of the set of simultaneous equations is made by an iterative process for small time increments.

The symbols used in this appendix are as follows:

A	area of conduction path or radiating surface, sq ft
c	specific heat, Btu/(lb)(°R)
F	configuration factor for radiant interchange (1.0)
k	thermal conductivity, Btu/(ft)(sec)(°R)
l	length of conduction path, ft
q	heat input, Btu/sec
T	temperature, °R
ΔT	increment in temperature
Δt	increment in time
V	volume, subdivisions of heat-transfer element, cu ft
ϵ	emissivity
ρ	weight density, lb/cu ft
σ	Stefan-Boltzmann constant, Btu/(sq ft)(sec)(°R) ⁴
Subscript:	
a	conductivity of air

Numerical subscripts indicate number of subdivision blocks in heat-transfer element.

An elemental section of the multipost heat shield is shown in figure 28. This section was used as a basic heat-transfer element to calculate the temperature distribution through the depth. Subdivision of the heat-transfer element into geometrical shapes is indicated by the numbered blocks in figure 28. Detail dimensions of the heat-transfer element are given in figure 3. For a small increment of time, heat-balance equations were written for each subdivision by considering heat loss and gain. In setting up heat-balance equations, net radiation exchange between the interstitial post of the heat-transfer element and that of surrounding posts was neglected. Configuration factors for radiant interchange were assumed to equal one for subdivisions in the face plates and corrugated sheet. Areas for subdivisions of the corrugated sheet were used as areas projected parallel to the face plates. A constant emissivity, $\epsilon = 0.46$, was assumed for stainless steel.

The following heat balance was used for each subdivision:

$$c\rho V \frac{\Delta T}{\Delta t} = \sum q_{\text{gained}} + \sum q_{\text{lost}}$$

The heat-balance equation for subdivision number 4 of figure 28 is given as follows as a typical equation:

$$\Delta T_4 = \frac{\Delta t}{c\rho V} \left[q - \epsilon\sigma(T_4)^4 A_4 + k \frac{A_{1-4}}{l_{1-4}}(T_1 - T_4) + k \frac{A_{4-5}}{l_{4-5}}(T_5 - T_4) \right. \\ \left. + k_a \frac{A_{4-13}}{l_{4-13}}(T_{13} - T_4) + \frac{1}{\frac{1}{\epsilon_4} + \frac{1}{\epsilon_{13}} - 1} F\sigma(T_{13}^4 - T_4^4) A_{4-13} \right]$$

The first term inside the brackets of the typical equation represents the heat input. The second term is the heat lost by block 4 by radiation from the outer surface. Conduction heat transfer with adjacent blocks is represented by the third and fourth terms. The air column between blocks 4 and 13 was assumed to be a conduction path. Conduction by air in this column is represented by the fifth term. Radiation exchange of blocks 4 and 13 is accounted for by the sixth term.

Twenty-nine equations are obtained from the heat-transfer element of figure 28. Since the variation of heat input with time was unknown, temperature-time history of block number 1 was measured in order to perform the calculations. A time increment of $\Delta t = 0.25$ seconds was found by trial calculations to be satisfactory for solution of the

equations. A simultaneous solution of these equations, for successive small increments of time, was made on an IBM 704 electronic data processing machine.

Equations approximating the temperature-time history of block number 1 are given in table IV. Variation of material properties with temperature used in solution of the heat-balance equations was approximated by the following equations:

For stainless steel 347

$$k = 0.001676 + 1.35 \times 10^{-6} \times T$$

$$c = 0.1088 + 20.0 \times 10^{-6} \times T$$

$$\rho = 494.2$$

For stainless steel 310

$$k = 0.001434 + 0.96527 \times 10^{-6} \times T$$

$$c = 0.1088 + 20.0 \times 10^{-6} \times T$$

$$\rho = 501.1$$

For air

$$k_a = 0.03437 \times 10^{-6} + 0.00828 \times 10^{-6} \times T - 1.2656 \times 10^{-12} T^2$$

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TABLE I.- ETHYLENE-JET SURVIVAL TESTS

Test panel	Ethylene-jet test number	Thickness of flat-plate graphite, in.	Grade of graphite	Fastener material	Angle of attack, deg	Ethylene-jet test conditions
Basic graphite heat shield	1	0.20	AGR	Zirconium dioxide	0	Stagnation temp. = 2,240° F Mach no. = 2.0 Static press. = 14.8 psia Dynamic press. = 5,535 lb/sq ft
Basic graphite heat shield	2	0.20	AGR	347 stainless steel	0	Stagnation temp. = 2,240° F Mach no. = 2.0 Static press. = 14.9 psia Dynamic press. = 5,590 lb/sq ft
Basic graphite heat shield	3	0.20	AGR	347 stainless steel	3	Stagnation temp. = 2,840° F Mach no. = 2.0 Static press. = 14.9 psia Dynamic press. = 5,575 lb/sq ft
Basic graphite heat shield	4	0.30	AGX	347 stainless steel	8	Stagnation temp. = 3,140° F Mach no. = 2.0 Static press. = 14.7 psia Dynamic press. = 5,460 lb/sq ft
Insulated multipost heat shield	5			347 stainless steel	3	Stagnation temp. = 1,850° F Mach no. = 2.0 Static press. = 14.9 psia Dynamic press. = 5,579 lb/sq ft
Stainless-steel-tile heat shield	6			Steel rivets	5	Stagnation temp. = 1,840° F Mach no. = 2.0 Static press. = 14.8 psia Dynamic press. = 5,927 lb/sq ft

TABLE II.- MEASURED TEMPERATURE-TIME HISTORIES DURING RADIANT-HEATER

TESTS FOR GRAPHITE HEAT SHIELDS

[Programed temperature rise, 40° F/sec]

(a) Tests made from room temperature to levels of 600° F

Time, sec	Without insulation				With bulk insulation				With radiation shields				With composite blanket			
	Temperature, °F, at thermocouples -															
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	70	70	71	71	70	70	70	70	69	69	71	71	70	70	71	71
2	70	70	71	71	70	70	70	70	69	69	71	71	70	70	71	71
4	83	83	71	72	81	82	70	71	82	81	71	71	80	74	71	72
6	180	178	72	73	185	186	71	72	186	181	72	72	180	143	72	73
8	269	267	73	74	280	278	72	73	280	276	73	73	275	254	73	74
10	351	348	74	75	364	362	74	74	368	364	74	74	361	317	75	75
12	434	430	76	77	448	447	74	75	456	450	75	75	446	401	76	77
14	520	516	78	79	536	535	76	77	548	541	77	76	534	487	77	79
16	603	598	80	82	600	600	77	78	616	608	78	78	620	575	79	82
18	643	638	83	84	660	660	79	80	682	674	79	79	662	625	80	84
20	665	661	85	87	681	680	80	81	710	701	80	80	686	659	81	85
80	663	664	134	147	661	665	100	111	780	776	107	126	680	680	110	131
140	661	662	181	201	670	671	126	144	777	777	144	169	682	681	148	176
200	663	663	230	249	676	677	159	176	768	768	172	208	686	685	188	217
260	660	661	273	292	676	676	188	203	752	752	217	245	684	684	225	253
320	653	652	310	326	669	670	217	231	735	734	241	276	677	677	258	285
380	654	654	340	354	671	671	251	257	730	729	276	302	677	676	287	311
440	661	661	367	378	676	676	269	280	732	731	301	325	683	682	312	334
500	668	667	389	398	682	682	290	300	737	736	322	345	688	688	334	353
560	658	658	407	415	673	673	309	318	725	724	341	363	678	678	352	370
620	654	653	421	428	668	668	325	333	716	715	356	377	672	672	367	384
680	656	656	432	439	669	668	340	346	716	715	369	389	673	673	380	395
740	658	658	442	448	670	670	352	358	717	716	381	400	673	673	388	405
800	661	661	450	456	671	671	363	368	719	717	391	409	675	675	400	414
860	663	663	458	463	674	674	373	377	720	719	400	418	676	676	409	422
920	666	665	465	469	676	676	382	386	723	721	408	425	678	678	416	428
980	669	669	470	473	679	678	390	394	725	723	416	432	679	679	424	435
1,040	669	669	476	479	679	678	394	400	724	723	422	437	678	679	428	440

TABLE II.- MEASURED TEMPERATURE-TIME HISTORIES DURING RADIANT-HEATER

TESTS FOR GRAPHITE HEAT SHIELDS - Continued

[Programed temperature rise, 40° F/sec]

(b) Tests made from room temperature to levels of 1,200° F

Time, sec	Without insulation				With bulk insulation				With radiation shields				With composite blanket			
	Temperature, °F, at thermocouples -															
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	74	74	76	76	74	74	75	76	74	74	76	76	74	74	76	76
2	80	76	76	77	78	77	76	76	78	78	77	76	76	76	76	76
4	142	122	77	77	136	132	75	76	139	132	77	77	125	114	77	77
6	240	217	78	78	240	239	75	77	243	238	79	78	232	207	78	78
8	324	304	79	79	329	328	77	78	333	330	79	78	323	293	79	79
10	406	386	80	80	410	408	78	79	417	414	80	79	404	370	80	81
12	477	466	81	82	489	486	80	80	500	496	81	80	484	447	81	82
14	558	548	83	84	572	571	81	81	589	584	83	81	567	528	83	85
16	636	628	85	87	653	652	82	83	675	669	84	83	648	608	84	87
18	697	690	88	89	715	715	83	84	742	735	86	85	733	689	86	88
20	778	772	90	91	799	799	85	86	832	823	87	86	797	750	87	91
22	857	851	94	95	881	881	87	88	920	910	89	88	879	829	89	94
24	936	930	98	98	983	984	90	90	1,008	997	91	91	961	902	94	98
26	1,016	1,010	103	102	1,046	1,047	91	92	1,097	1,085	93	93	1,044	977	94	101
28	1,098	1,092	109	107	1,131	1,133	93	94	1,187	1,168	96	96	1,123	1,060	97	104
30	1,169	1,158	115	110	1,204	1,208	95	97	1,269	1,242	99	98	1,196	1,140	99	107
90	1,213	1,218	301	277	1,283	1,276	157	168	1,446	1,438	179	186	1,295	1,291	179	208
150	1,224	1,227	450	434	1,331	1,326	231	254	1,465	1,463	275	293	1,331	1,326	272	316
210	1,225	1,228	579	563	1,352	1,349	313	339	1,452	1,450	368	396	1,342	1,338	364	414
270	1,225	1,228	684	665	1,358	1,357	394	418	1,435	1,432	454	487	1,345	1,340	449	499
330	1,222	1,225	788	752	1,368	1,367	467	488	1,431	1,427	512	564	1,351	1,347	522	570
390	1,225	1,227	866	823	1,377	1,376	533	550	1,431	1,426	596	630	1,358	1,353	586	630
450	1,224	1,227	909	870	1,373	1,374	589	604	1,423	1,418	651	684	1,353	1,349	637	678
510	1,225	1,228	929	896	1,369	1,369	635	648	1,417	1,412	698	728	1,348	1,343	677	716
570	1,225	1,228	939	912	1,366	1,366	674	684	1,413	1,407	735	763	1,343	1,339	710	747
630	1,225	1,228	944	921	1,364	1,364	705	714	1,410	1,404	764	790	1,339	1,335	735	770
690	1,225	1,228	947	927	1,361	1,362	731	737	1,409	1,403	785	809	1,337	1,332	754	787
750	1,221	1,223	948	930	1,355	1,356	750	756	1,406	1,399	799	823	1,330	1,326	767	799
810	1,219	1,222	948	931	1,352	1,354	766	771	1,404	1,398	809	832	1,326	1,322	776	806
870	1,219	1,222	948	932	1,352	1,353	778	782	1,406	1,399	815	838	1,326	1,322	782	812
930	1,220	1,222	949	933	1,351	1,352	786	790	1,406	1,400	819	843	1,327	1,323	786	815
990	1,219	1,237	950	935	1,349	1,351	792	795	1,407	1,400	822	846	1,326	1,323	788	817

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TABLE II.- MEASURED TEMPERATURE-TIME HISTORIES DURING RADIANT-HEATER

TESTS FOR GRAPHITE HEAT SHIELDS - Concluded

[Programed temperature rise, 40° F/sec]

(c) Tests made from room temperature to levels of 1,800° F

Time, sec	Without insulation				With bulk insulation				With radiation shields				With composite blanket			
	Temperature, °F, at thermocouples -															
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	120	119	130	129	124	124	140	139	121	121	137	135	120	120	134	133
2	143	141	131	131	151	150	140	139	151	136	137	135	139	139	135	134
4	246	243	132	132	267	262	141	140	259	221	139	136	239	237	136	135
6	347	342	133	133	372	367	142	141	357	315	139	137	345	338	137	137
8	426	421	135	133	451	448	143	142	434	392	141	138	430	418	138	138
10	504	498	136	135	528	527	145	143	511	467	142	139	510	496	139	139
12	581	576	139	137	605	610	145	144	588	542	143	140	590	573	140	140
14	662	656	141	140	686	691	146	146	667	621	145	141	673	654	142	143
16	755	735	144	142	767	773	148	147	745	700	147	142	755	734	143	144
18	835	812	149	146	846	851	150	149	821	777	148	144	834	812	145	146
20	894	871	152	148	909	911	151	150	880	836	150	146	895	872	146	148
24	1,044	1,025	163	156	1,075	1,069	156	154	1,033	987	154	149	1,054	1,026	150	153
28	1,202	1,191	179	167	1,246	1,237	161	158	1,193	1,142	159	154	1,222	1,189	155	159
32	1,365	1,357	201	182	1,421	1,410	168	164	1,354	1,292	166	159	1,408	1,358	162	167
36	1,505	1,499	225	197	1,569	1,556	174	169	1,485	1,417	173	165	1,564	1,507	167	175
40	1,651	1,647	261	220	1,727	1,712	184	176	1,619	1,555	182	172	1,727	1,672	176	185
44	1,775	1,771	305	247	1,859	1,831	195	184	1,727	1,663	191	181	1,870	1,821	185	197
104	1,828	1,834	934	754	1,907	1,916	391	357	1,926	1,882	391	374	2,065	2,061	372	432
164	1,848	1,855	1,263	1,121	1,910	1,926	622	582	1,973	1,947	607	613	1,975	1,983	579	690
224	1,852	1,855	1,382	1,274	1,886	1,911	860	786	1,983	1,961	795	820	1,946	1,965	761	897
284	1,855	1,852	1,447	1,337	1,870	1,900	1,051	939	1,983	1,966	949	981	1,939	1,963	899	1,042
344	1,868	1,870	1,483	1,403	1,859	1,891	1,188	1,045	1,988	1,977	1,037	1,077	1,900	1,955	990	1,136
404	1,865	1,871	1,474	1,405	1,842	1,876	1,277	1,113	1,988	1,977	1,094	1,138	1,893	1,907	1,046	1,193
464	1,870	1,873	1,516	1,435	1,827	1,863	1,334	1,156	1,989	1,979	1,129	1,179	1,892	1,907	1,079	1,228
524	1,870	1,873	1,521	1,445	1,814	1,852	1,370	1,183	1,975	1,977	1,153	1,207	1,889	1,904	1,100	1,249
584	1,869	1,871	1,525	1,452	1,802	1,840	1,395	1,201	1,972	1,977	1,169	1,227	1,886	1,902	1,114	1,262
644	1,865	1,867	1,525	1,456	1,787	1,823	1,409	1,212	1,987	1,977	1,180	1,239	1,881	1,898	1,123	1,267
704	1,865	1,867	1,525	1,458	1,179	1,815	1,421	1,221	1,989	1,977	1,188	1,248	1,882	1,899	1,129	1,276
764	1,865	1,869	1,527	1,462	1,771	1,807	1,433	1,229	1,991	1,977	1,195	1,254	1,886	1,902	1,135	1,282
824	1,866	1,869	1,527	1,465	1,768	1,802	1,443	1,235	1,994	1,977	1,200	1,259	1,884	1,906	1,139	1,287
884	1,869	1,871	1,529	1,467	1,764	1,798	1,451	1,241	1,996	1,977	1,204	1,263	1,870	1,909	1,142	1,292
944	1,871	1,873	1,532	1,470	1,760	1,793	1,457	1,246	1,998	1,981	1,208	1,267	1,868	1,915	1,146	1,295

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TABLE III.- MEASURED TEMPERATURE-TIME HISTORIES DURING RADIANT-HEATER

TESTS FOR GRAPHITE HEAT SHIELDS

[Programed temperature rise, 80° F/sec]

(a) Tests made from room temperature to levels of 600° F

Time, sec	Without insulation				With bulk insulation				With radiation shields				With composite blanket			
	Temperature, °F, at thermocouples -															
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	73	72	75	75	73	73	75	75	72	72	75	75	73	73	76	75
2	73	73	75	75	73	73	75	75	72	72	75	75	73	73	76	75
4	73	72	75	75	73	73	75	75	72	72	76	75	73	73	76	75
6	75	74	75	75	75	76	75	75	75	74	75	75	73	73	76	75
8	197	185	77	77	210	213	77	77	226	203	77	76	76	94	77	77
10	381	364	80	79	401	401	79	80	418	385	79	78	93	166	79	80
12	537	521	83	81	560	562	81	82	578	537	81	79	130	264	82	83
72	652	656	140	140	637	655	103	109	766	761	107	113	614	594	107	123
132	661	663	196	201	663	676	130	145	783	782	140	155	642	611	141	166
192	662	664	249	255	675	685	163	181	774	772	175	195	651	616	179	207
252	667	668	298	302	686	695	197	216	770	768	210	232	660	626	216	245
312	667	669	339	341	691	699	230	248	761	760	241	265	662	630	251	279
372	654	655	373	373	681	688	259	277	742	740	270	294	657	627	281	308
432	668	669	400	399	693	700	286	303	748	746	295	318	662	633	307	332
492	664	665	422	420	690	696	309	324	741	739	317	339	663	636	330	353
552	656	657	438	436	681	687	329	343	727	725	335	356	654	629	348	370
612	656	657	450	448	680	685	345	358	722	720	350	371	652	628	363	384
672	657	658	460	457	680	685	359	372	720	718	363	382	652	629	376	395
732	660	660	468	465	681	685	372	383	720	719	376	393	654	631	386	405
792	662	662	475	471	682	687	382	393	721	719	383	402	655	633	395	414
852	664	665	481	478	683	688	391	401	723	720	391	409	656	635	403	421
912	666	666	486	482	684	689	398	409	723	721	398	416	658	637	410	427

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TABLE III.- MEASURED TEMPERATURE-TIME HISTORIES DURING RADIANT-HEATER

TESTS FOR GRAPHITE HEAT SHIELDS - (Continued)

[Programed temperature rise, 80° F/sec]

(b) Tests made from room temperature to levels of 1,200° F

Time, sec	Without insulation				With bulk insulation				With radiation shields				With composite blanket			
	Temperature, °F, at thermocouples -															
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	76	75	78	78	76	76	77	78	76	76	79	78	76	77	78	78
2	76	75	78	78	77	77	77	77	76	76	78	78	76	77	79	78
4	77	75	78	78	76	76	77	78	76	76	79	78	77	77	78	78
6	107	102	79	79	111	115	78	79	121	111	79	78	77	79	79	79
8	283	265	81	81	302	303	80	81	317	288	81	80	85	125	81	81
10	458	439	84	83	482	481	82	83	498	460	83	81	112	216	83	84
12	572	554	86	84	599	598	84	85	616	572	85	83	147	295	85	86
14	709	693	91	87	738	736	86	87	757	708	88	85	210	406	87	89
16	835	820	96	91	862	860	90	89	884	833	90	87	287	517	89	92
18	950	936	102	95	976	976	92	92	1,001	948	93	89	372	611	92	96
78	1,240	1,248	357	294	1,270	1,310	198	173	1,447	1,433	184	187	1,123	1,166	171	208
138	1,242	1,248	561	491	1,329	1,367	296	280	1,487	1,475	296	313	1,207	1,248	271	331
198	1,242	1,247	712	646	1,353	1,386	397	387	1,486	1,475	404	432	1,243	1,280	374	444
258	1,245	1,249	815	758	1,362	1,393	488	483	1,479	1,468	499	537	1,259	1,291	467	543
318	1,248	1,251	880	830	1,362	1,391	567	565	1,470	1,460	581	623	1,263	1,292	545	622
378	1,247	1,251	919	875	1,357	1,383	630	629	1,465	1,455	645	674	1,261	1,286	606	681
438	1,246	1,249	942	903	1,351	1,376	677	679	1,460	1,451	695	739	1,258	1,282	653	725
498	1,248	1,252	956	921	1,350	1,374	714	718	1,460	1,451	733	777	1,259	1,281	688	757
558	1,248	1,251	965	933	1,348	1,371	740	746	1,461	1,452	767	800	1,258	1,279	714	781
618	1,247	1,251	971	940	1,347	1,369	760	768	1,462	1,454	783	827	1,258	1,278	733	798
678	1,248	1,251	975	945	1,346	1,369	775	784	1,461	1,454	798	842	1,258	1,277	750	811
738	1,247	1,250	978	949	1,347	1,369	786	797	1,462	1,455	810	854	1,258	1,277	761	821
798	1,248	1,251	980	951	1,349	1,371	793	806	1,465	1,457	820	863	1,260	1,278	767	828

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TABLE III.- MEASURED TEMPERATURE-TIME HISTORIES DURING RADIANT-HEATER

TESTS FOR GRAPHITE HEAT SHIELDS - Concluded

[Programed temperature rise, 800° F/sec]

(c) Tests made from room temperature to levels of 1,800° F

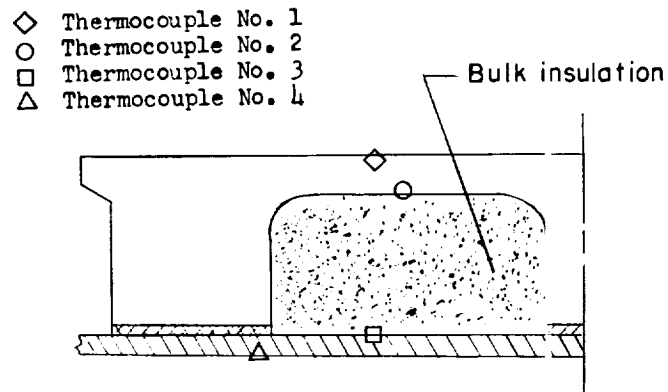
Time, sec	Without insulation				With bulk insulation				With radiation shields				With composite blanket			
	Temperature, °F, at thermocouples -				Temperature, °F, at thermocouples -				Temperature, °F, at thermocouples -				Temperature, °F, at thermocouples -			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	152	151	170	169	156	158	177	175	151	150	176	174	148	151	161	160
2	151	151	170	169	156	158	176	175	150	150	176	174	148	150	161	160
4	160	158	170	169	165	163	176	175	172	181	176	174	149	151	160	160
6	292	275	172	171	290	231	178	178	357	382	178	176	155	158	163	162
8	449	418	175	173	435	322	180	179	541	559	180	177	170	170	165	164
10	596	555	178	175	577	427	183	181	707	715	182	179	197	191	167	167
12	699	654	181	178	680	510	184	183	822	824	184	180	227	214	169	170
14	827	778	187	181	808	620	187	185	961	955	186	182	277	255	171	173
16	946	896	193	185	928	728	189	188	1,089	1,075	189	183	342	311	174	177
18	1,063	1,011	200	190	1,045	838	193	191	1,212	1,189	192	186	421	382	176	181
20	1,144	1,092	207	194	1,127	921	196	193	1,296	1,269	195	188	487	443	178	185
22	1,250	1,199	218	200	1,205	1,061	202	196	1,404	1,369	199	191	588	541	181	189
24	1,349	1,301	231	209	1,294	1,134	206	199	1,505	1,462	203	194	698	651	184	195
26	1,446	1,398	248	218	1,382	1,233	211	202	1,594	1,545	208	198	823	778	188	208
86	1,811	1,802	888	672	1,888	1,942	527	371	2,014	1,970	426	395	1,842	1,871	367	439
146	1,823	1,811	1,220	1,030	1,939	1,974	733	596	2,012	1,984	632	629	1,880	1,907	565	693
206	1,827	1,812	1,355	1,219	1,928	1,958	890	794	2,004	1,975	798	826	1,867	1,893	732	889
266	1,833	1,816	1,408	1,310	1,922	1,949	1,027	940	2,002	1,976	923	968	1,861	1,886	856	1,022
326	1,834	1,816	1,451	1,348	1,918	1,943	1,121	1,040	1,998	1,974	1,012	1,065	1,858	1,880	942	1,109
386	1,837	1,818	1,477	1,379	1,920	1,943	1,189	1,108	1,999	1,975	1,072	1,129	1,856	1,878	1,000	1,163
446	1,828	1,807	1,488	1,401	1,911	1,934	1,232	1,151	1,986	1,964	1,110	1,170	1,846	1,865	1,037	1,197
506	1,827	1,804	1,492	1,419	1,907	1,930	1,260	1,179	1,984	1,961	1,135	1,196	1,844	1,861	1,061	1,218
566	1,828	1,803	1,496	1,423	1,908	1,931	1,282	1,198	1,986	1,964	1,153	1,214	1,844	1,861	1,077	1,232
626	1,831	1,805	1,500	1,433	1,911	1,934	1,299	1,211	1,989	1,967	1,165	1,227	1,847	1,863	1,089	1,242
686	1,832	1,804	1,504	1,438	1,911	1,936	1,311	1,221	1,988	1,966	1,174	1,234	1,848	1,863	1,098	1,251
746	1,831	1,800	1,505	1,440	1,910	1,935	1,321	1,228	1,987	1,966	1,181	1,243	1,847	1,862	1,104	1,257
990	1,832	1,799	1,507	1,440	1,910	1,935	1,327	1,233	1,988	1,966	1,185	1,247	1,847	1,863	1,108	1,260

TABLE IV.- MEASURED TEMPERATURE-TIME HISTORY OF MULTIPOST HEAT SHIELD
AT THERMOCOUPLE NUMBER 1, BLOCK NUMBER 1

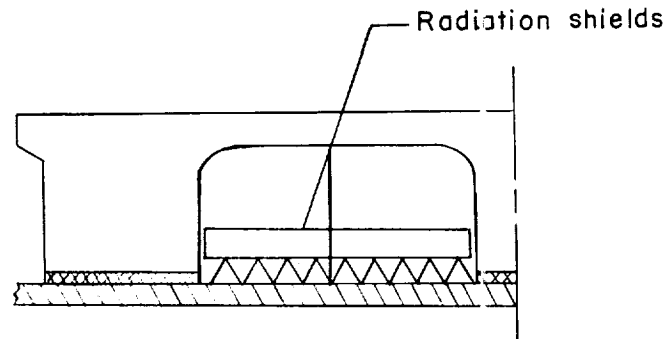
[T_1 , temperature of block no. 1, $^{\circ}\text{R}$; t , time in seconds]

Time, sec	Equation of straight line approximating measured temperature-time variation of block no. 1
0 to 8	$T_1 - 22.825t - 542 = 0$
8 to 60	$T_1 - 20.813t - 558.092 = 0$
60 to 66	$T_1 - 17.383t - 763.900 = 0$
66 to 67	$T_1 - 12.8t - 1066.4 = 0$
67 to 68	$T_1 - 1924 = 0$

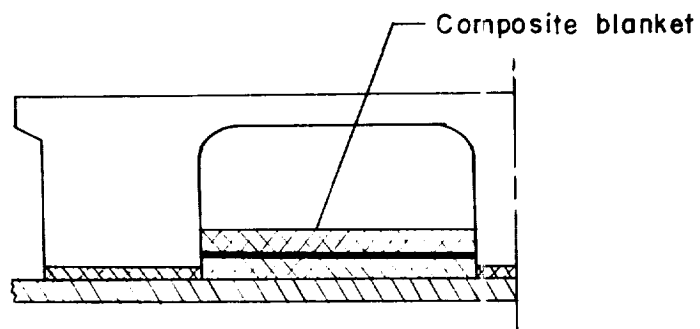
L
1
5
2
4



(c) Sectional view A-A. Basic graphite heat shield with bulk insulation. Thermocouple locations are typical for graphite heat shields.

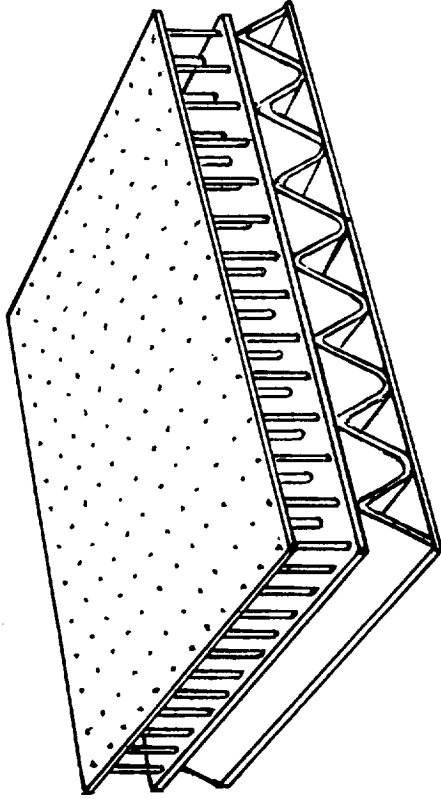


(d) Sectional view A-A. Basic graphite heat shield with radiation shields.

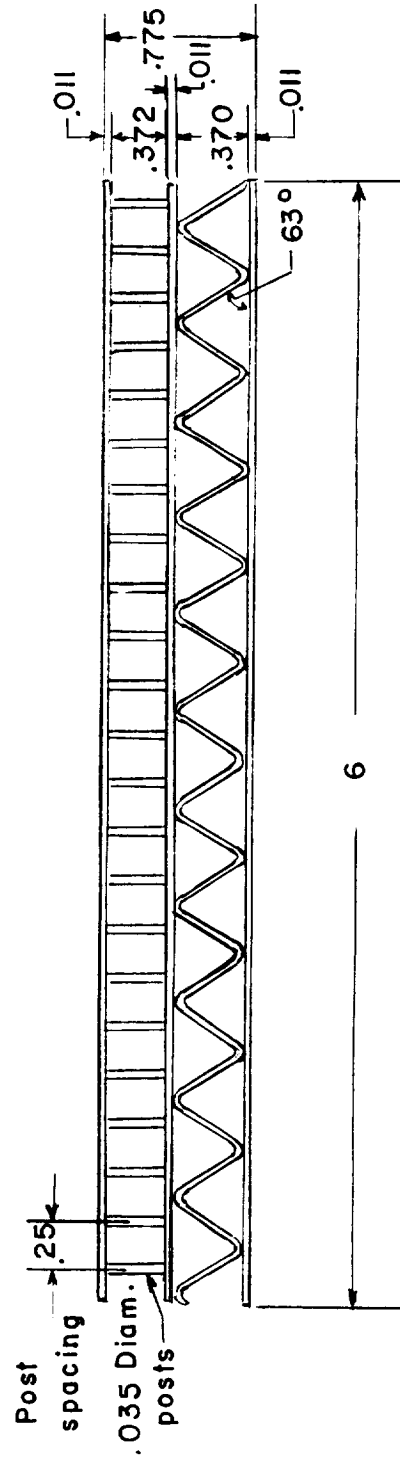


(e) Sectional view A-A. Basic graphite heat shield with composite blanket.

Figure 1.- Concluded.



(a) Perspective sketch.



(b) Cross section.

Figure 2.- Schematic sketch of the multipost heat shield. Dimensions in inches.

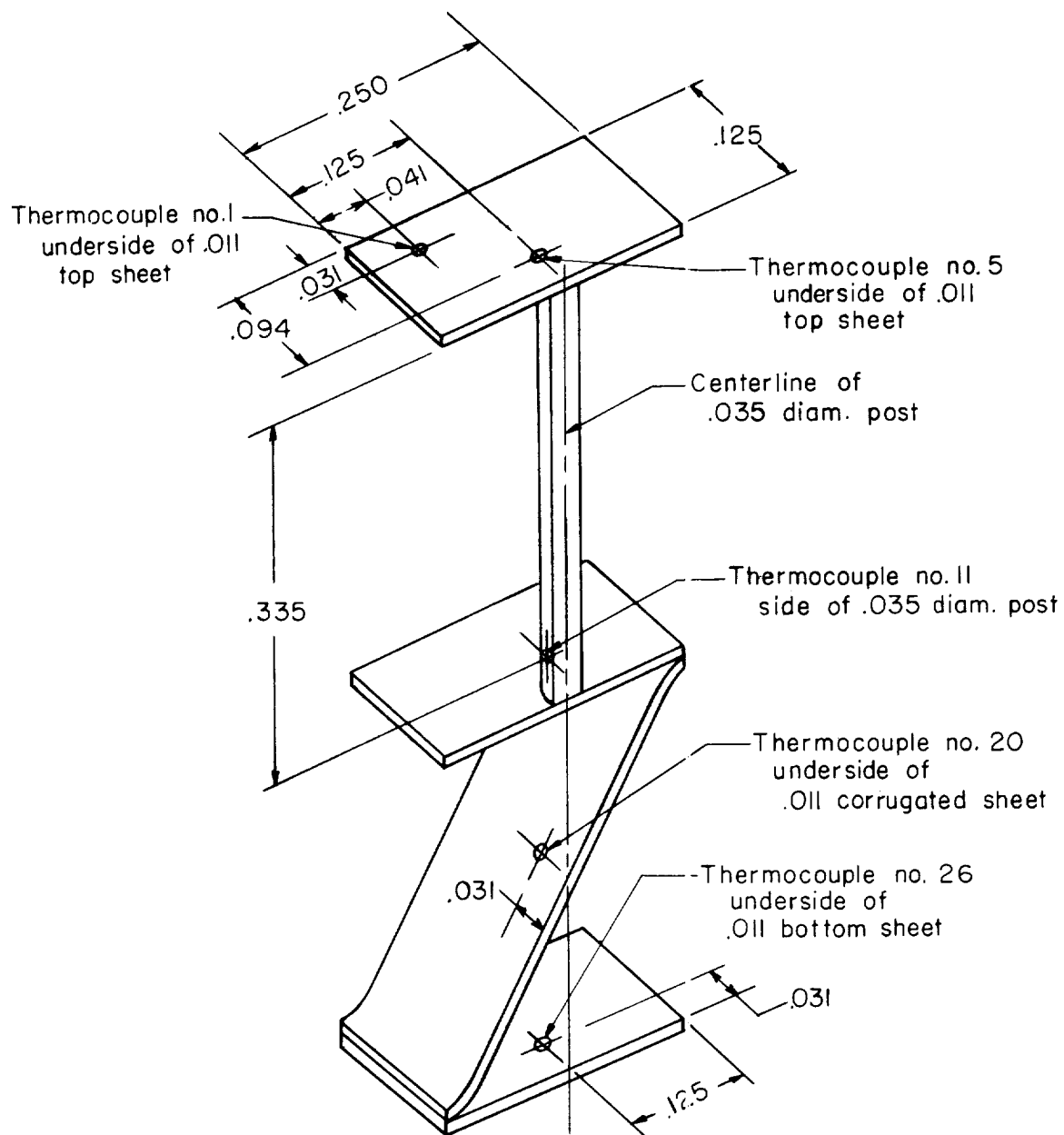
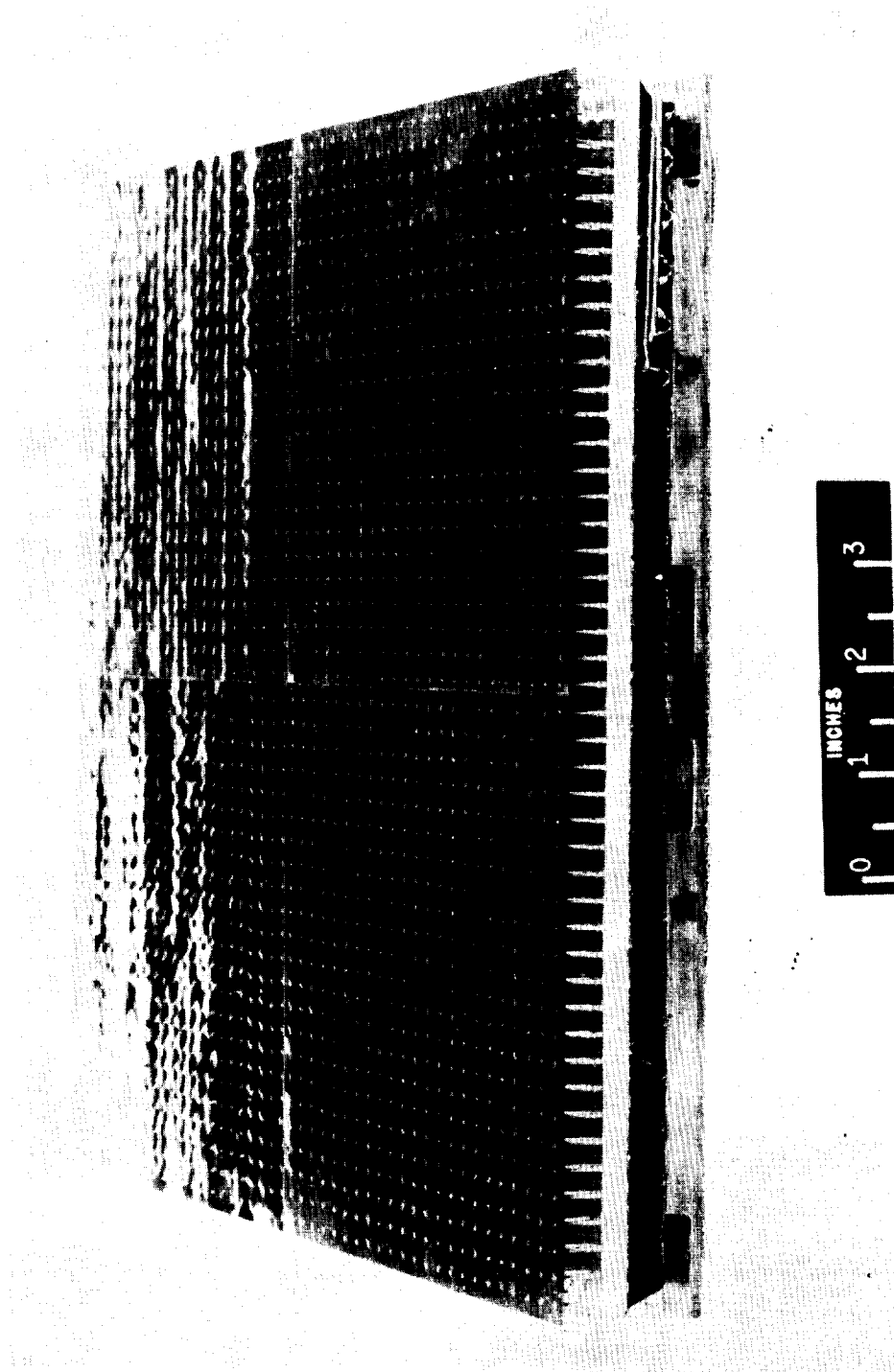


Figure 3.- Structural element of multipost heat shield showing thermocouple locations. Dimensions in inches.



(a) Photograph of insulated multi-post heat shield. L-59-5282

Figure 4.- Insulated multi-post heat shield. Dimensions in inches.

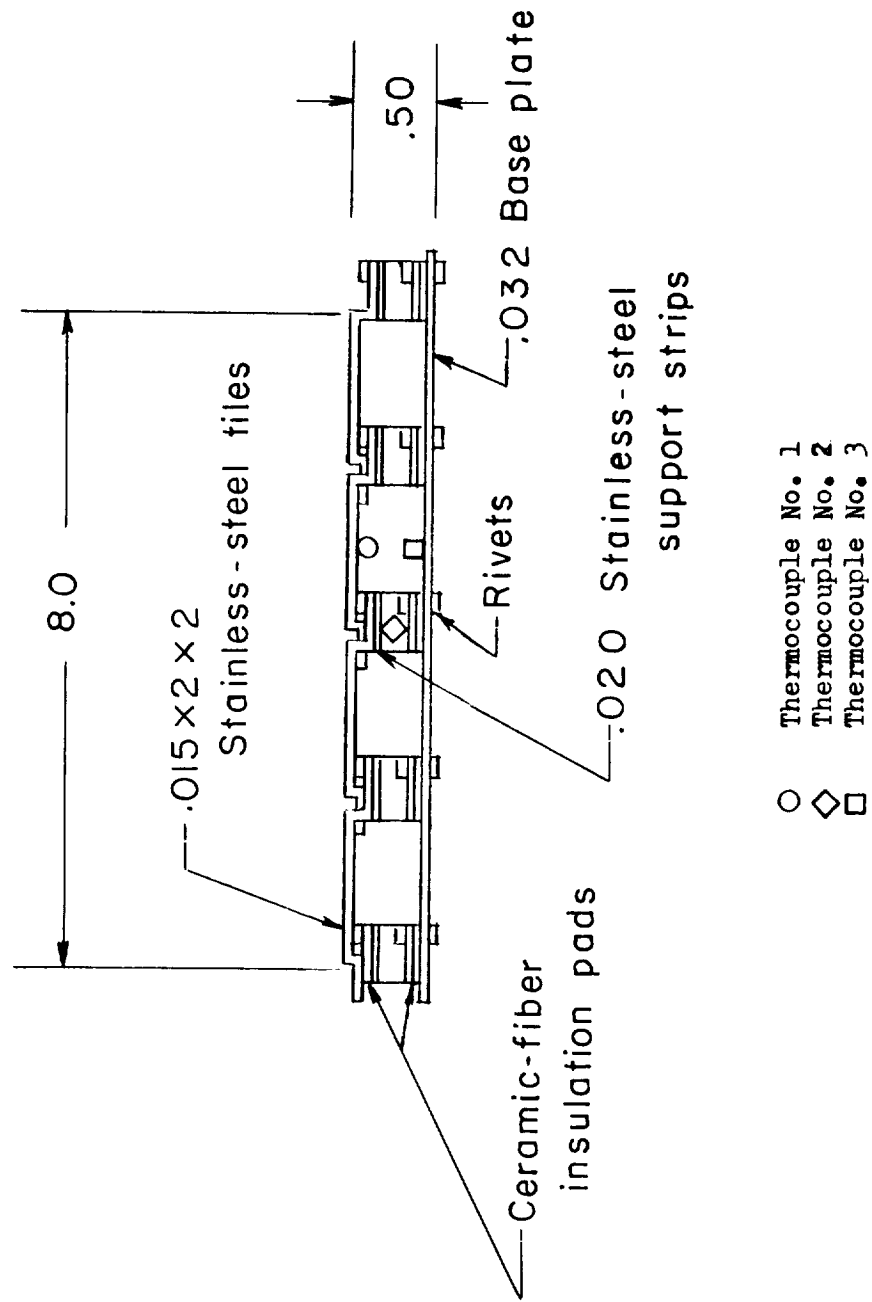


Figure 5.- Cross section of stainless-steel-tile heat shield. Dimensions in inches.

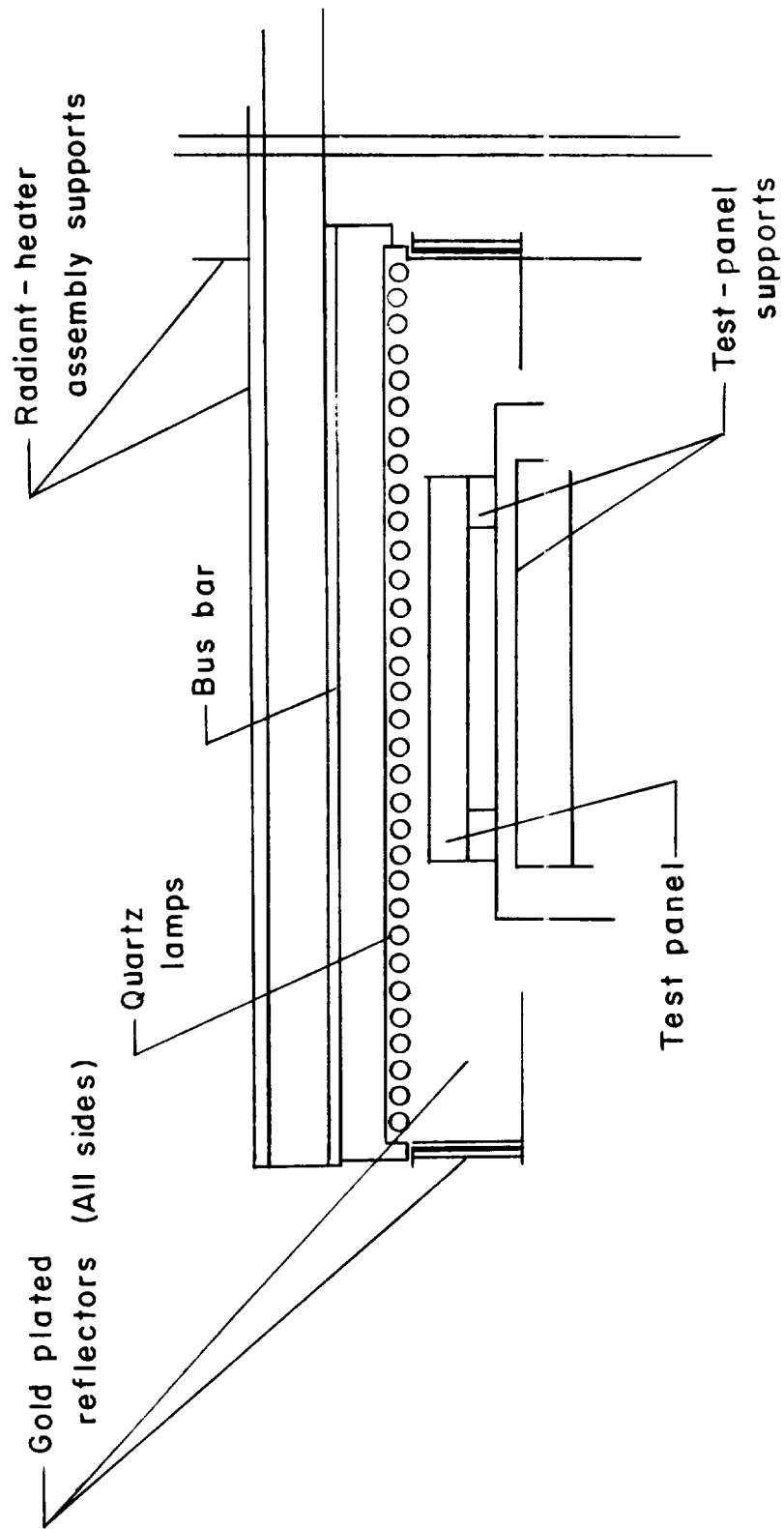
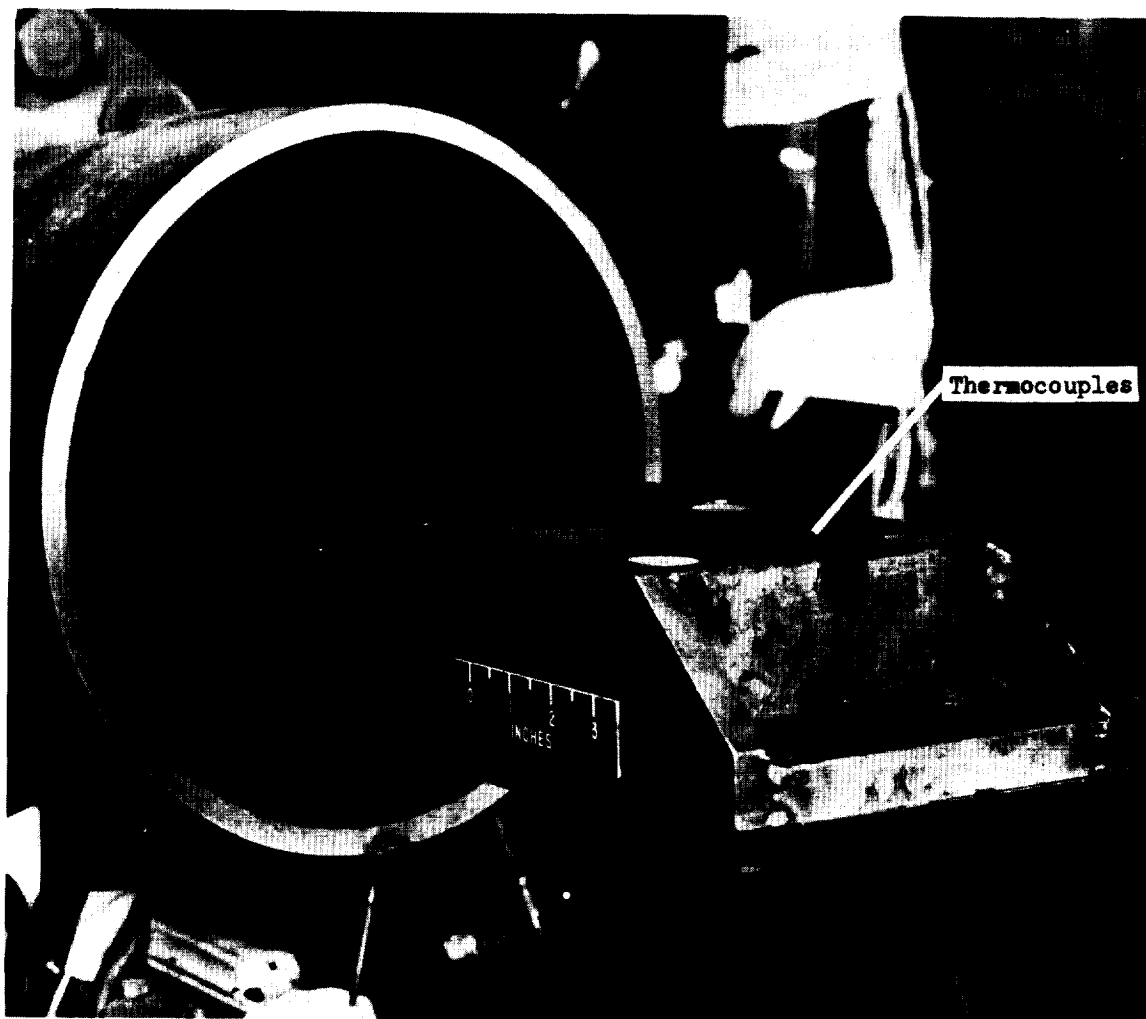


Figure 6.- Schematic sketch of radiant-heater test setup.



L-58-1224a.1

Figure 7.- Photograph of typical test setup for ethylene-jet survival tests. Test setup for basic graphite heat shield illustrated.

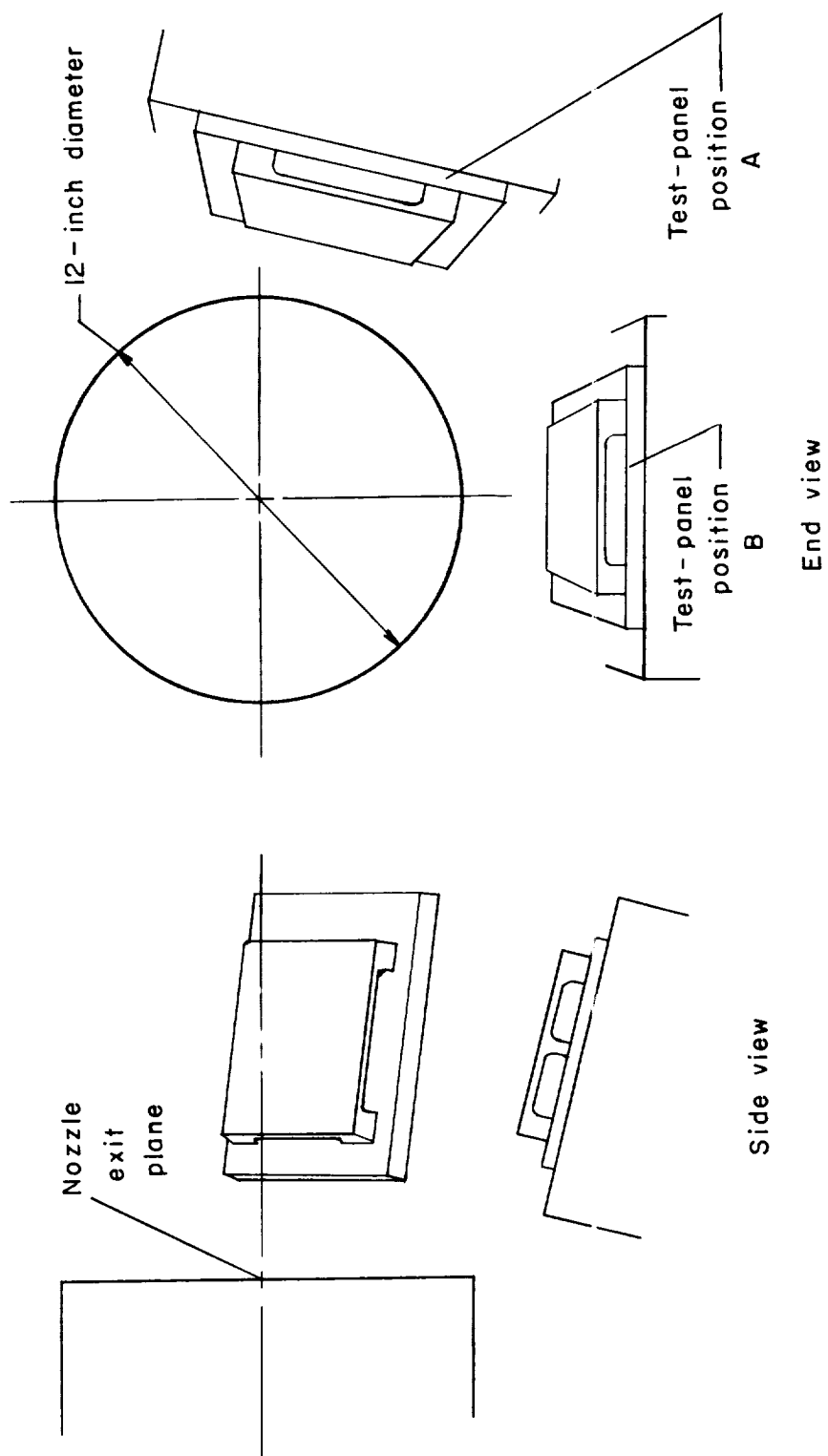


Figure 8.- Schematic sketch of acoustic test setup of basic graphite heat shield.

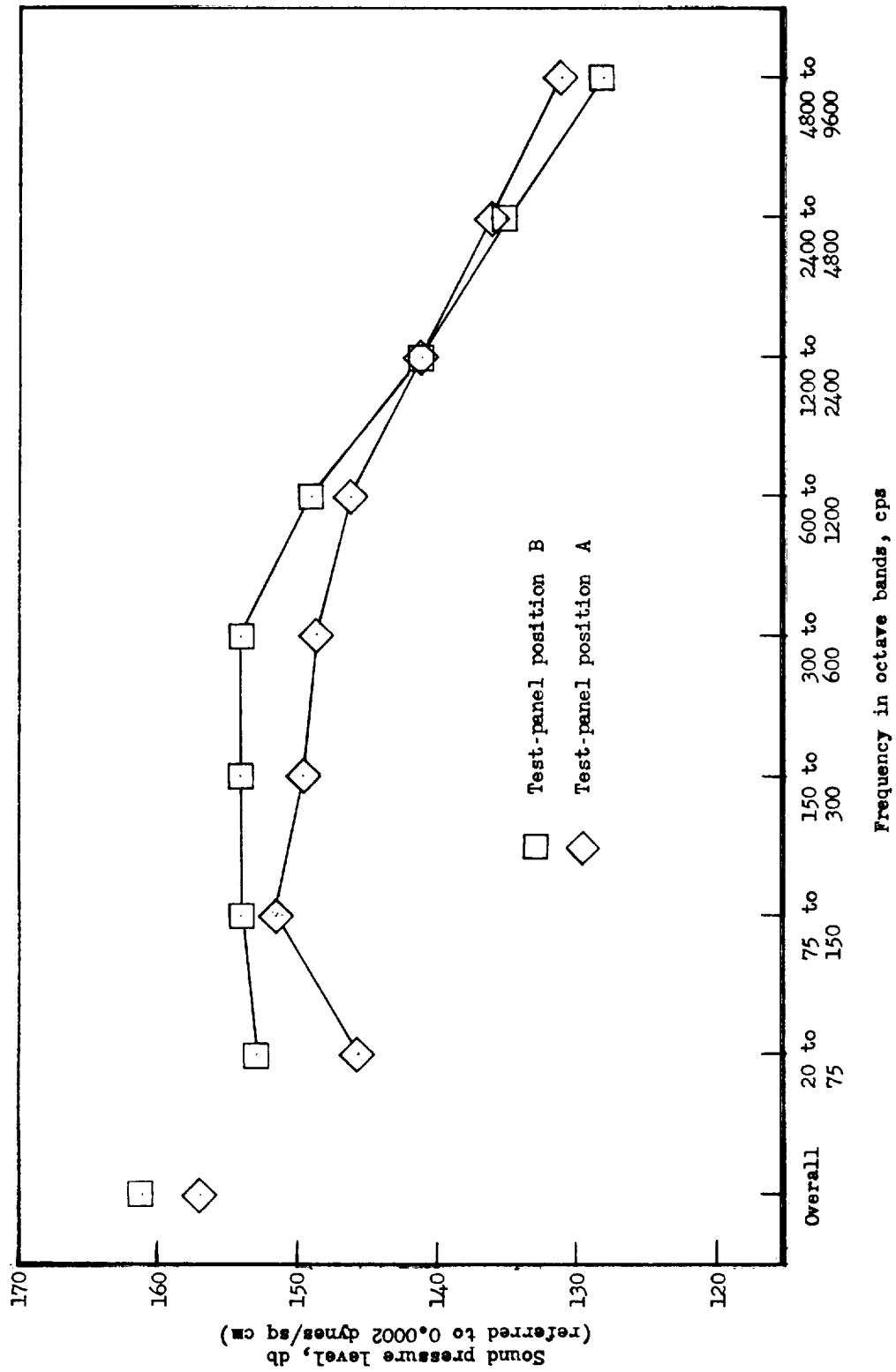


Figure 9.- Noise spectra. Acoustic facility; basic graphite heat shield.

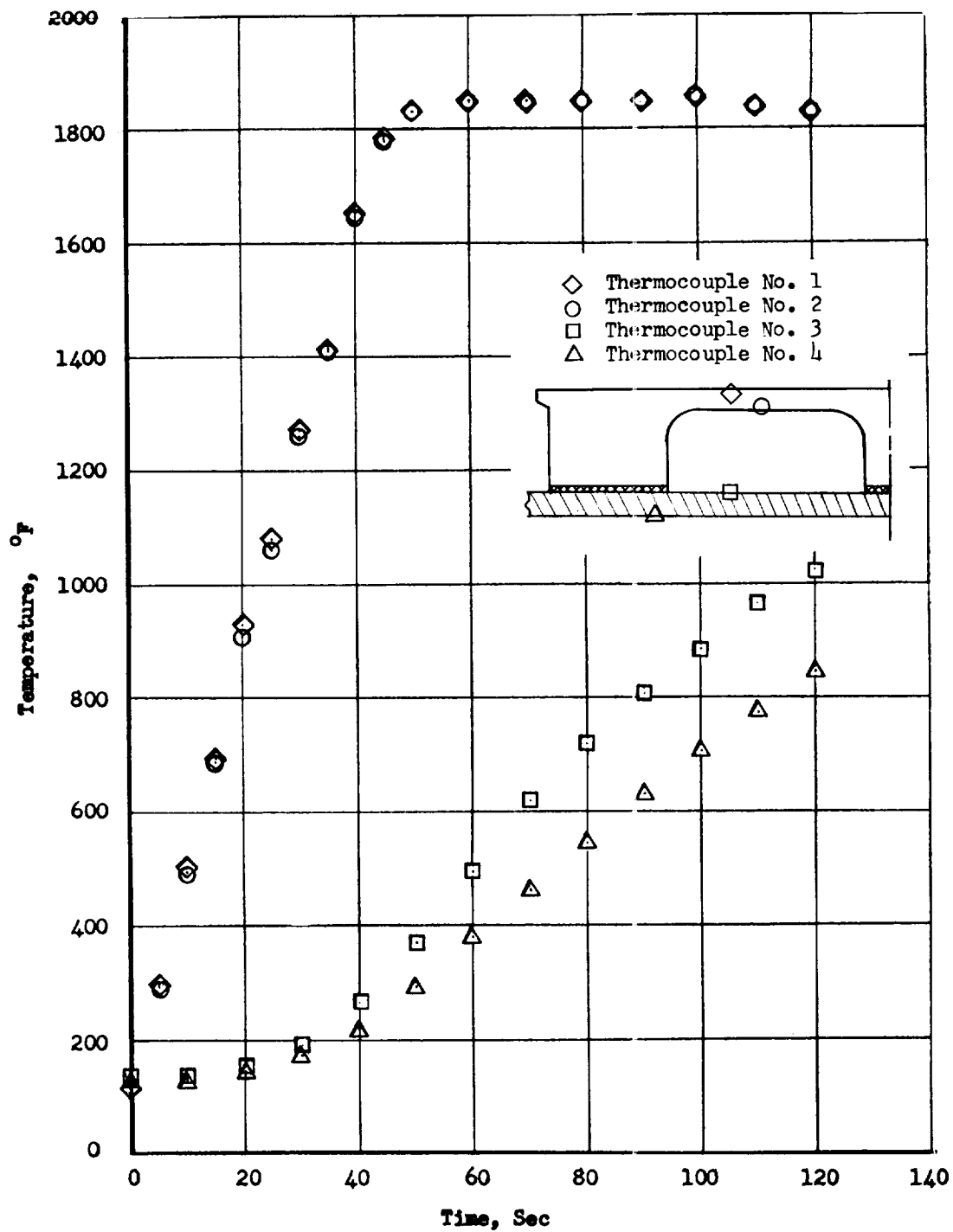


Figure 10.- Measured temperature-time histories for the basic graphite heat shield without insulation. Radiant-heater test.

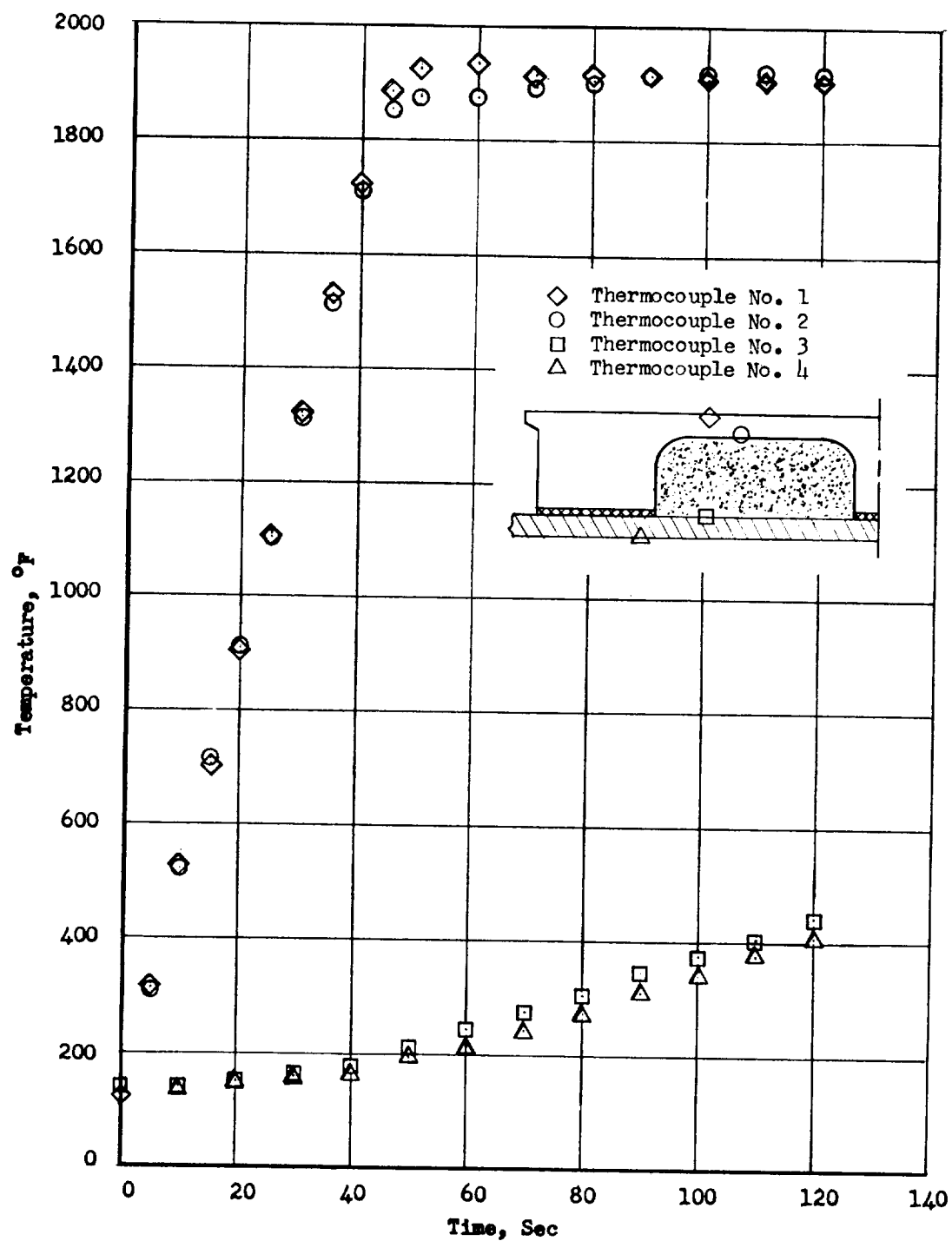


Figure 11.- Measured temperature-time histories for the basic graphite heat shield with bulk insulation. Radiant-heater test.

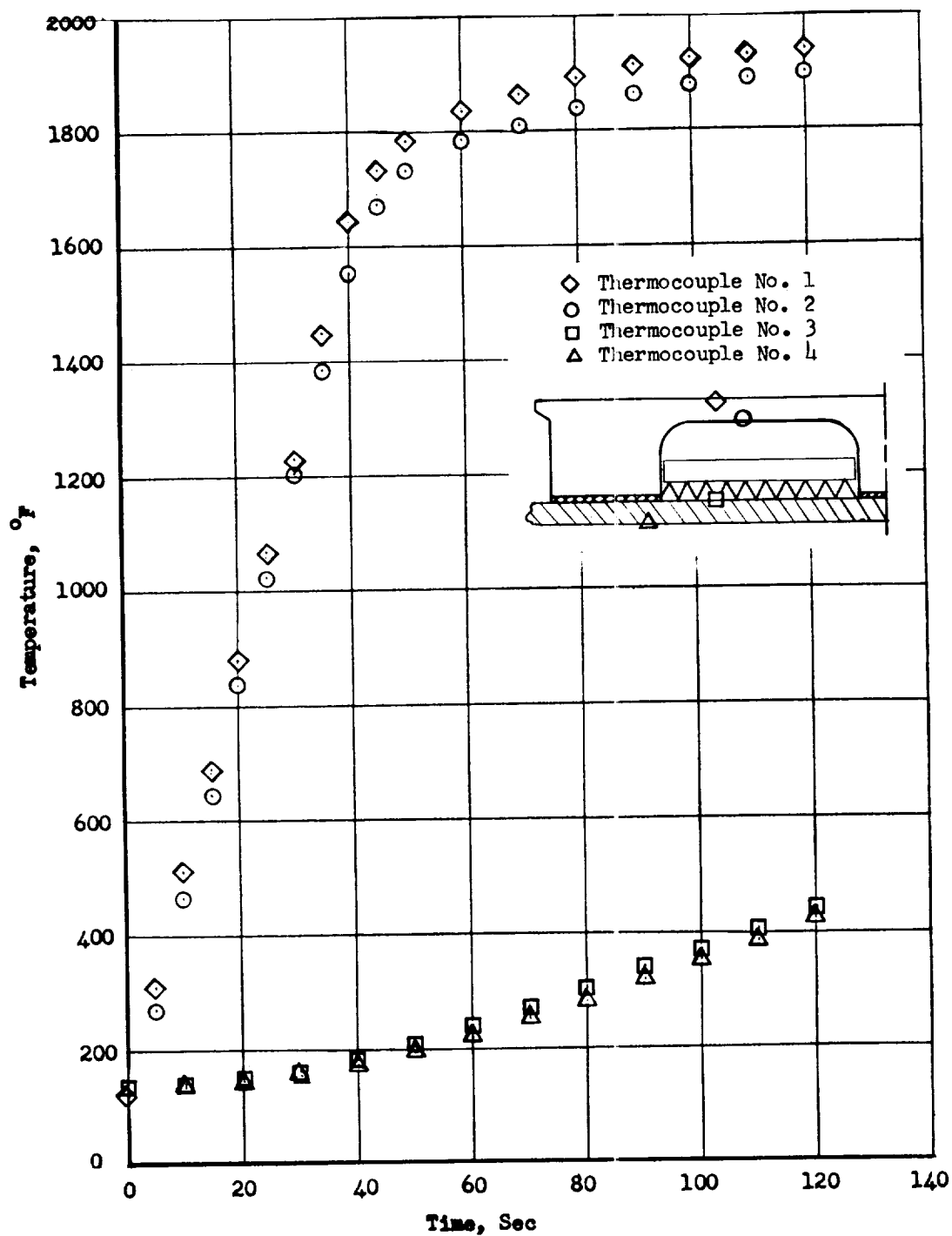


Figure 12.- Measured temperature-time histories for the basic graphite heat shield with radiation shields. Radiant-heater test.

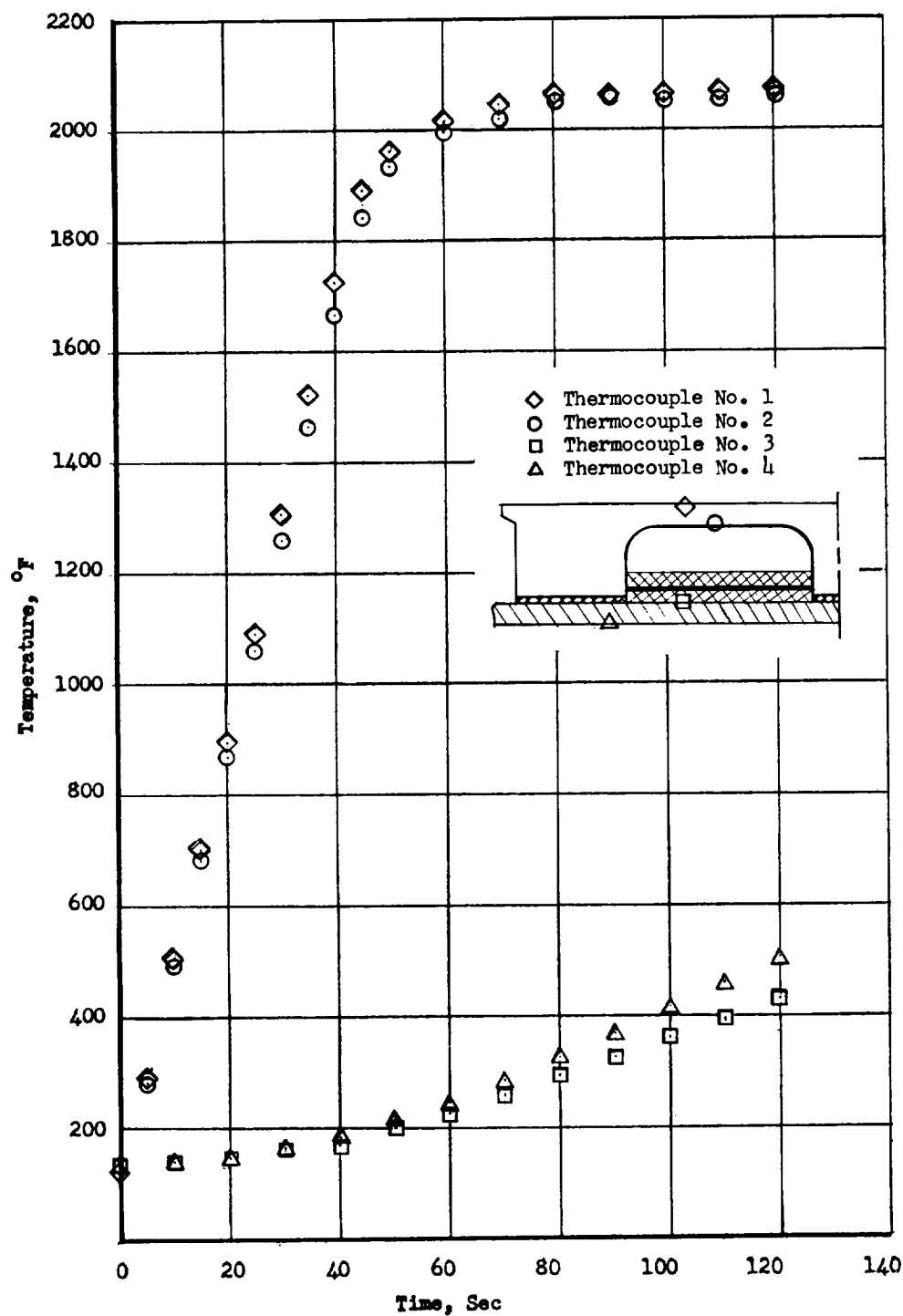
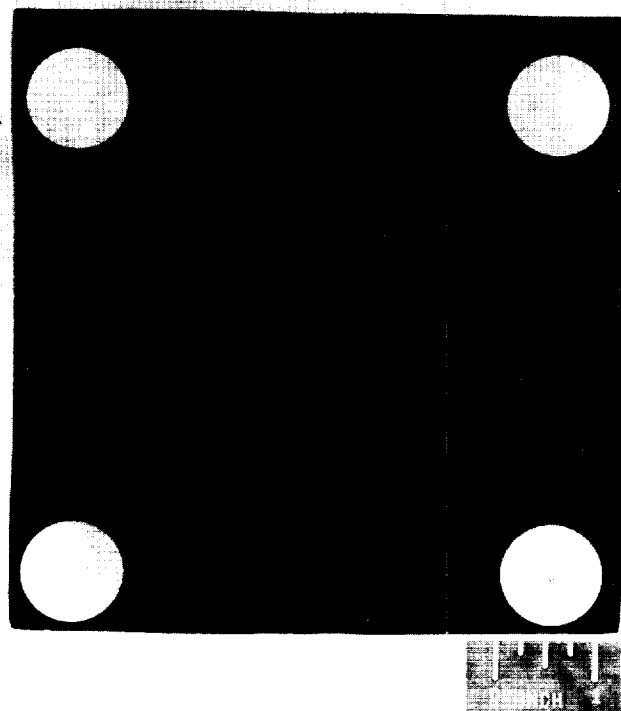
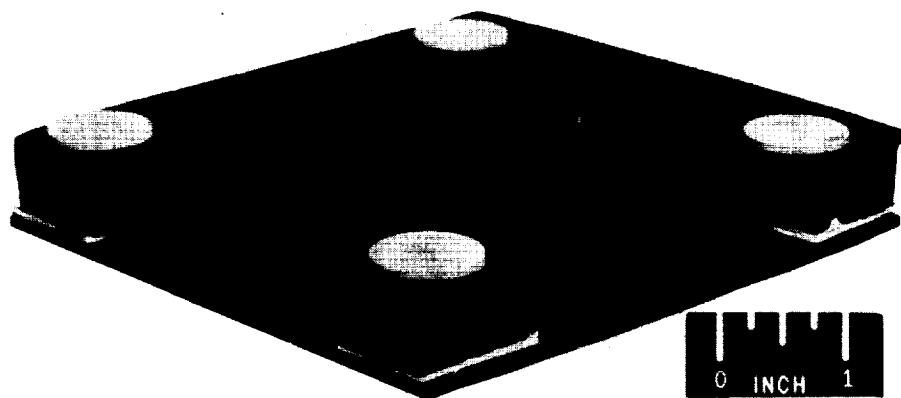


Figure 13.- Measured temperature-time histories for the basic graphite heat shield with composite blanket. Radiant-heater test.



(a) Plan view.

L-60-2374

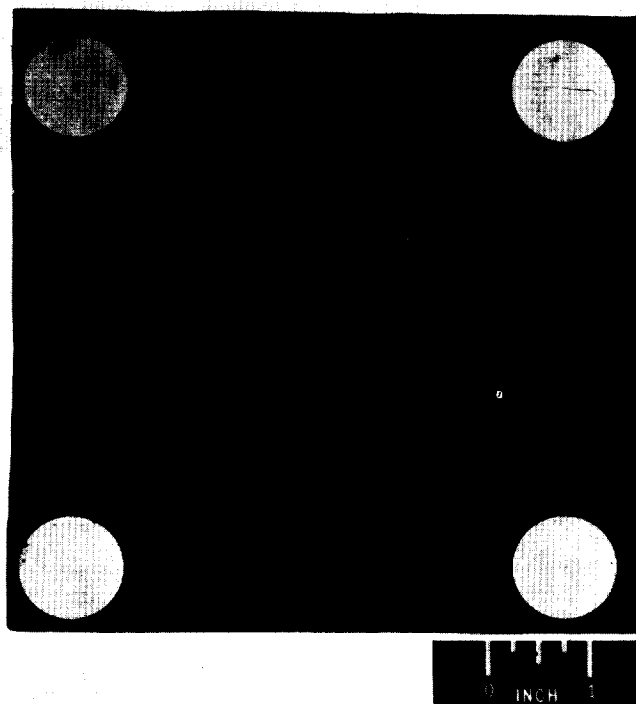


(b) Perspective view.

L-60-2370

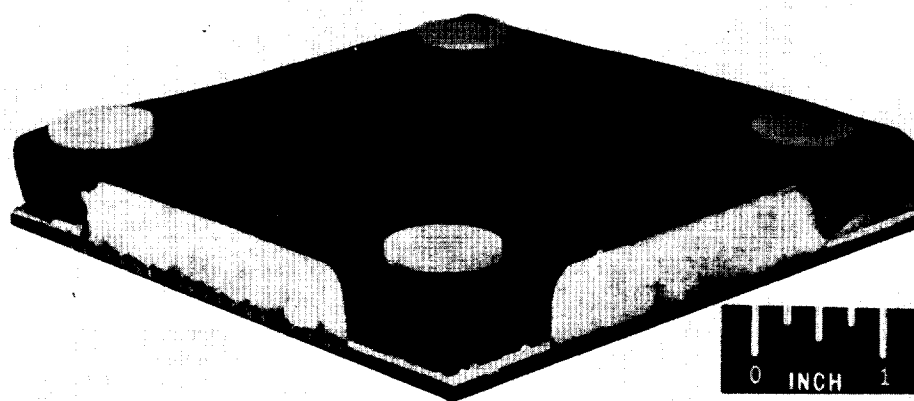
Figure 14.- Photograph of basic graphite heat shield without insulation,
after six radiant-heater exposures.

L-1524



(a) Plan view.

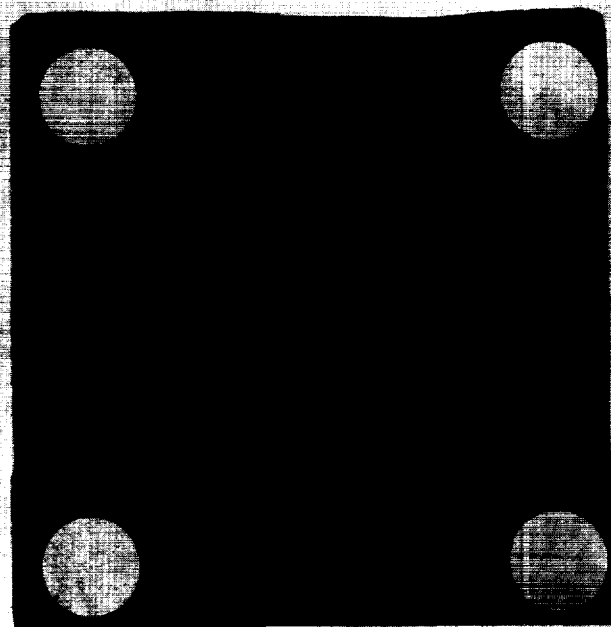
L-60-2377



(b) Perspective view.

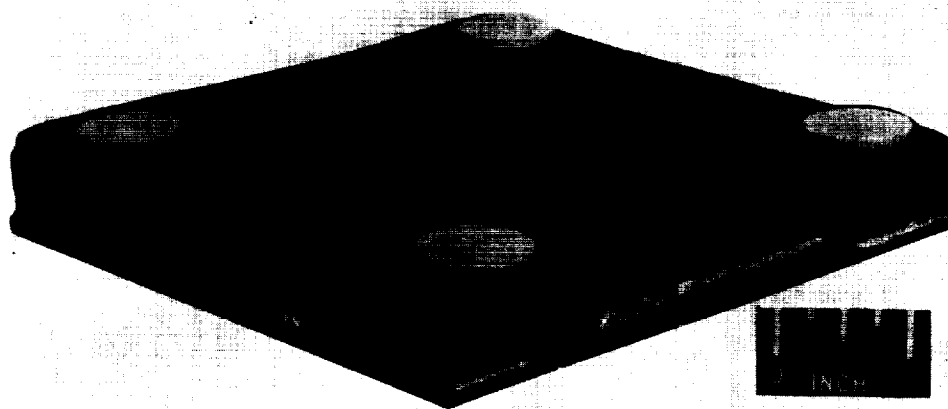
L-60-2373

Figure 15.- Photograph of basic graphite heat shield with bulk insulation, after six radiant-heater exposures.



(a) Plan view.

L-60-2375

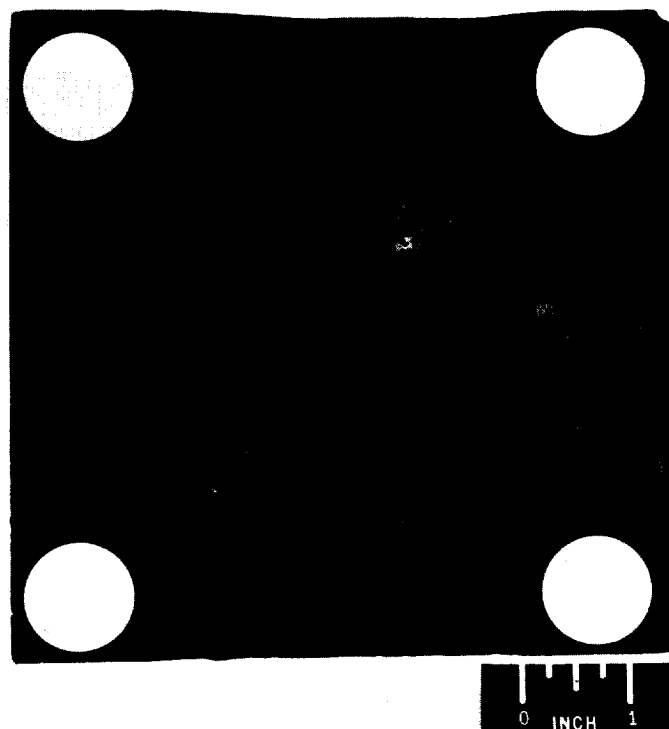


(b) Perspective view.

L-60-2371

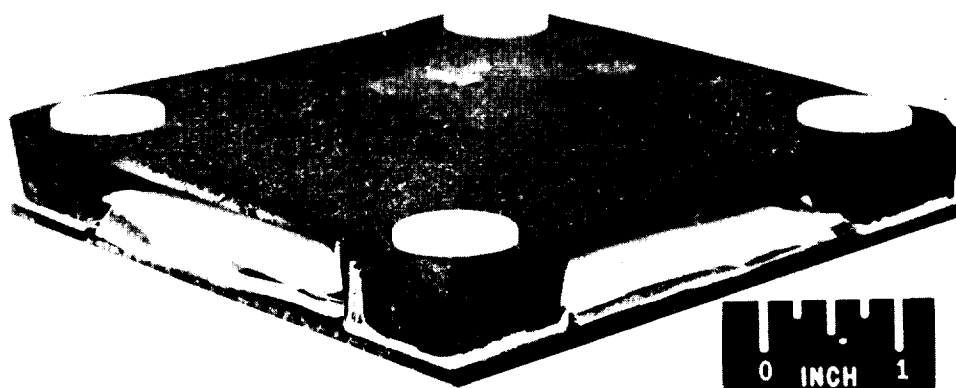
Figure 16.- Photograph of basic graphite heat shield with radiation shields, after six radiant-heater exposures.

L-1524



(a) Plan view.

L-60-2376



(b) Perspective view.

L-60-2372

Figure 17.- Photograph of basic graphite heat shield with composite blanket, after six radiant-heater exposures.

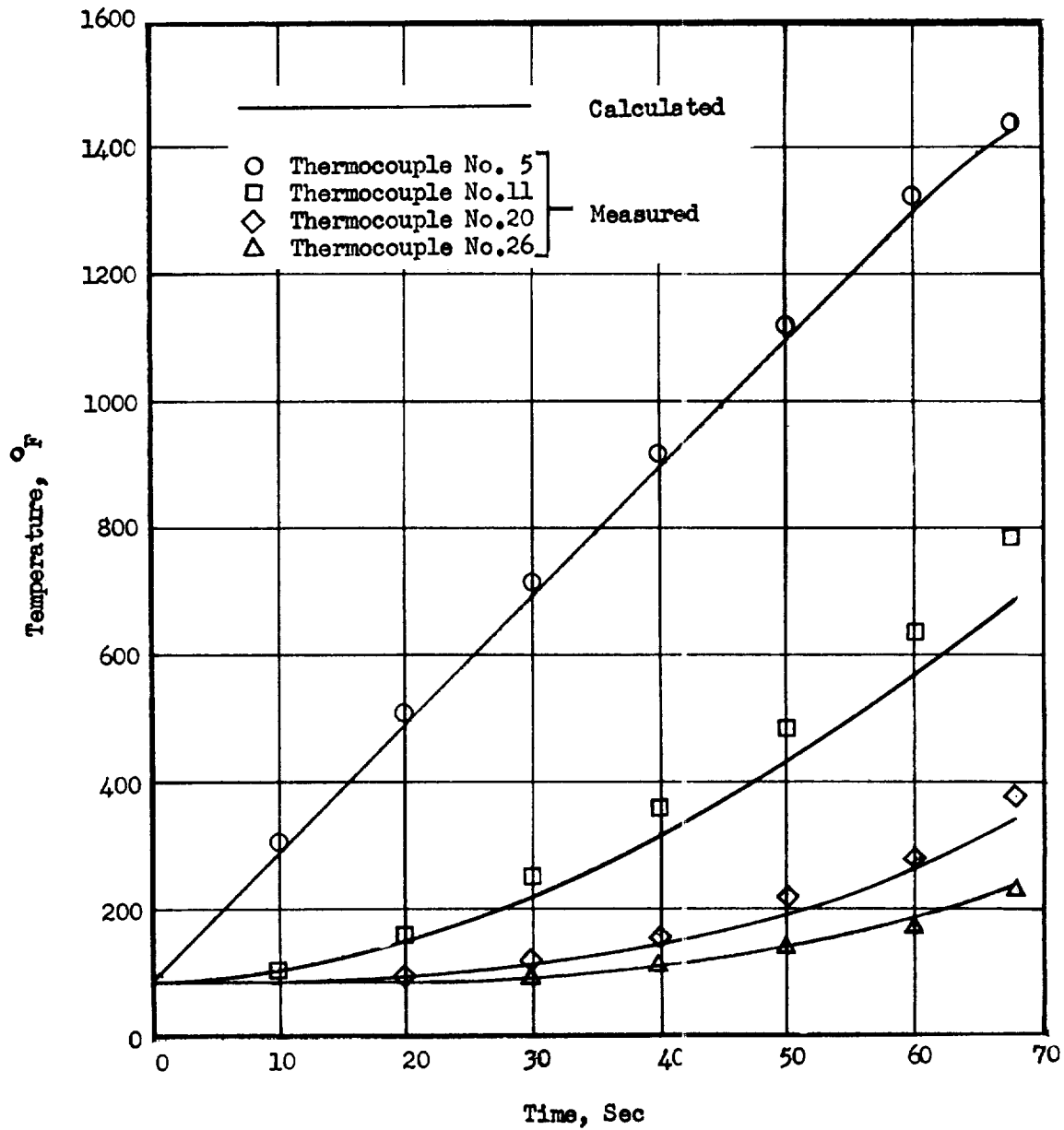


Figure 18.- Comparison of calculated and measured temperature-time histories for the multipost heat shield. Radiant-heater test.

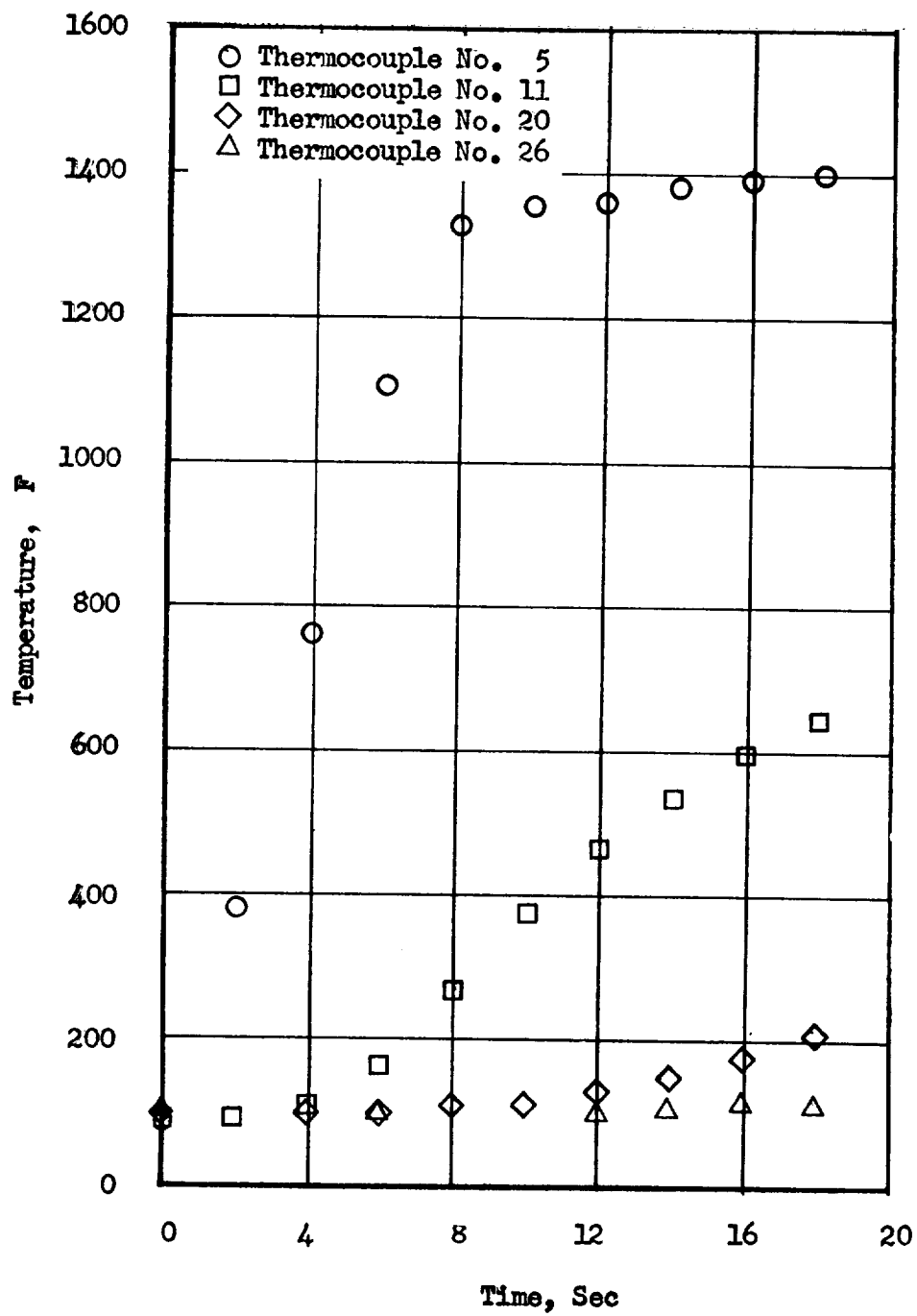
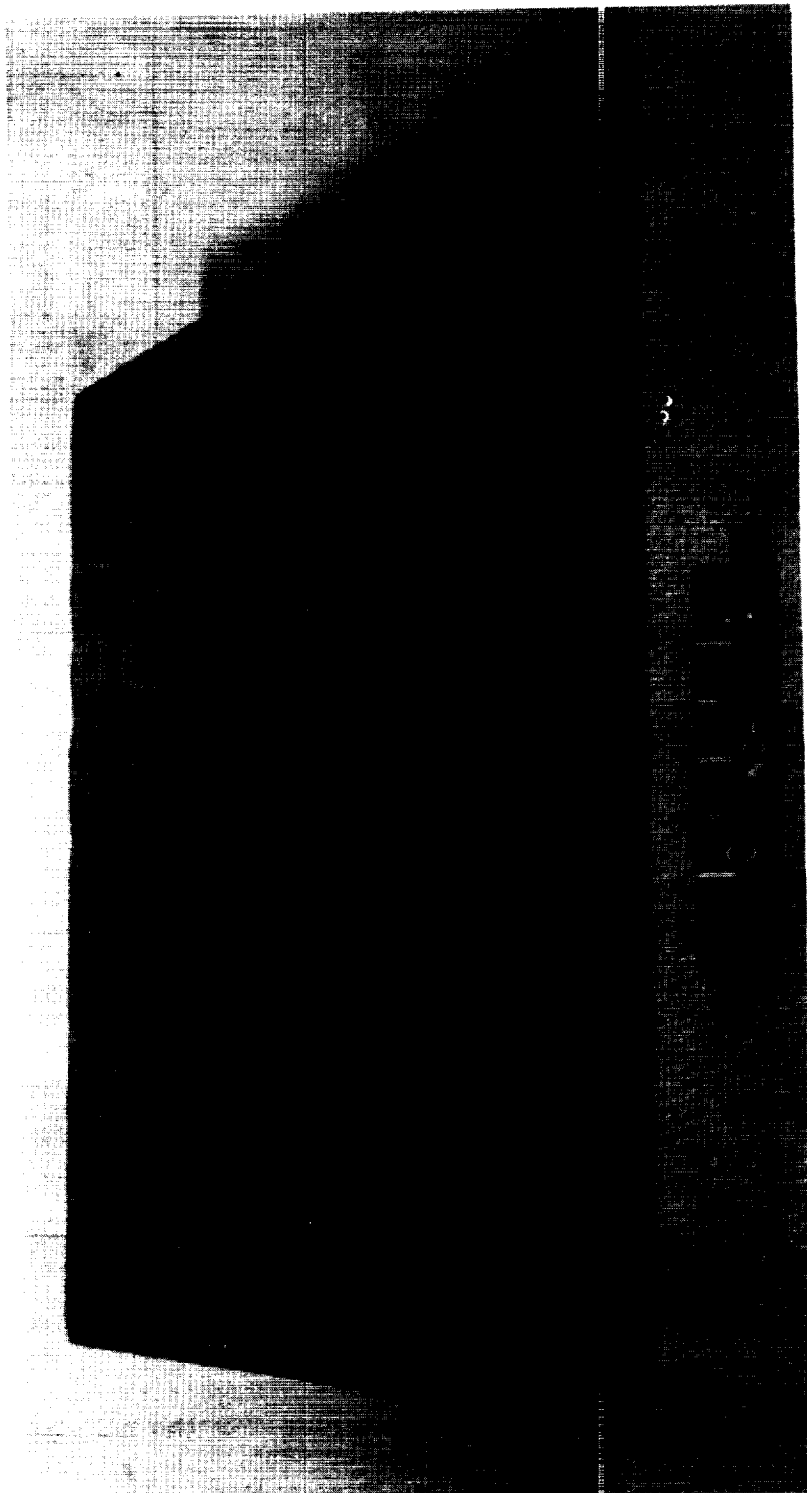


Figure 19.- Measured temperature-time histories for the multipost heat shield. Radiant-heater test.



L-60-4403

Figure 20.- Photograph of the multipost heat shield after radiant-heater tests.

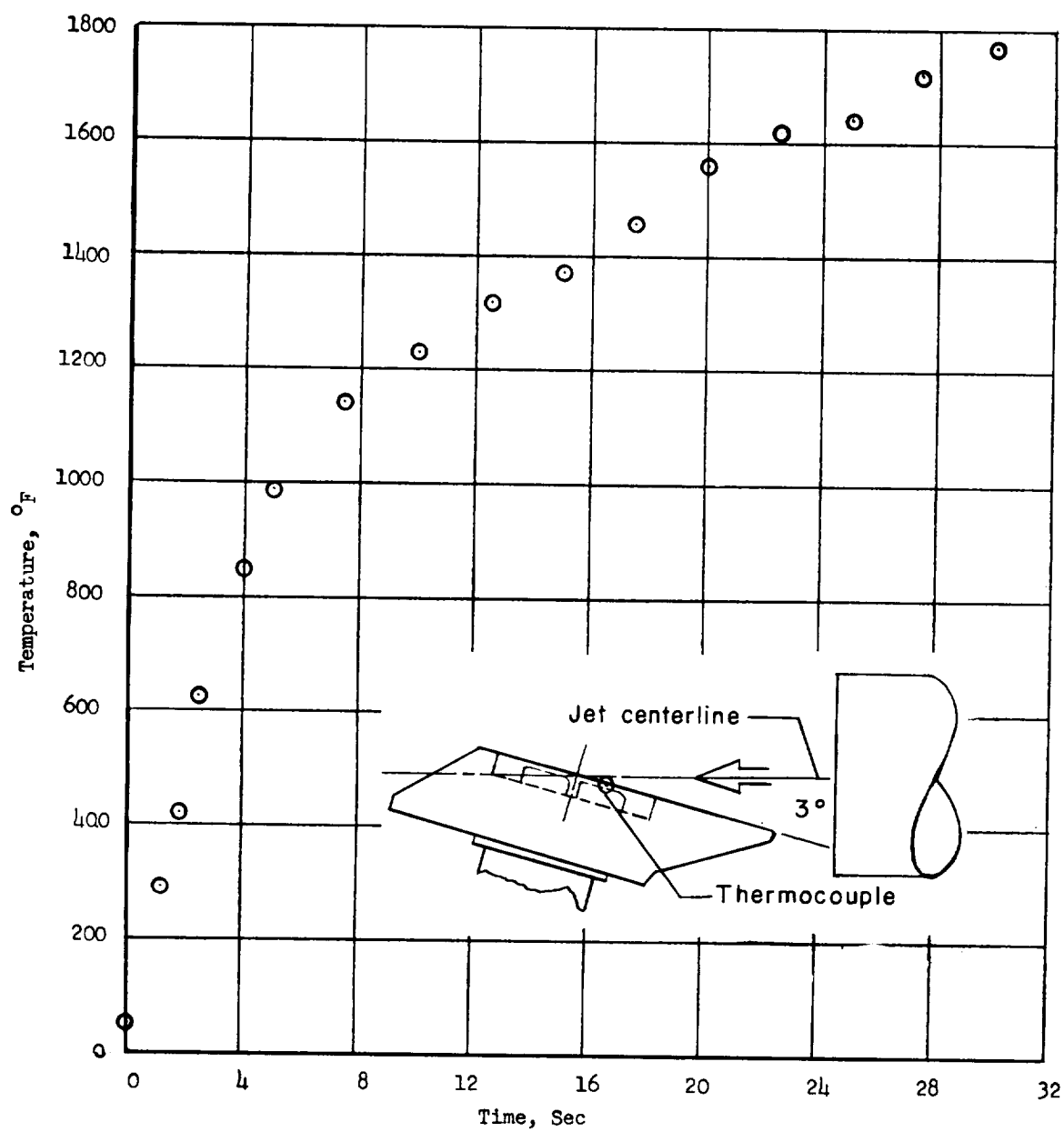


Figure 21.- Measured temperature-time history for basic graphite heat shield without insulation. 0.20-inch-thick flat plate; ethylene-jet survival test.

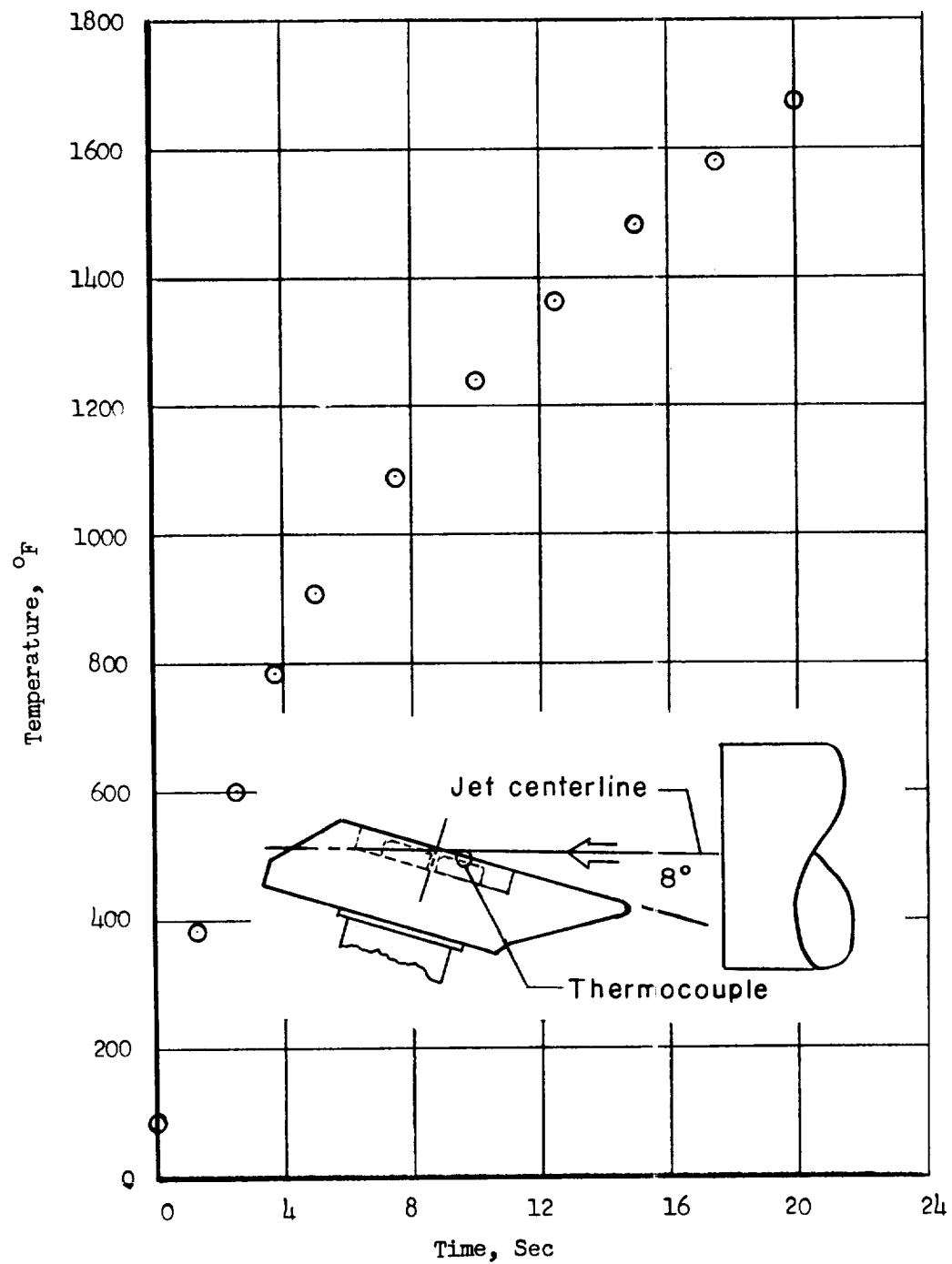


Figure 22.- Measured temperature-time history for basic graphite heat shield without insulation. 0.30-inch-thick flat plate; ethylene-jet survival test.

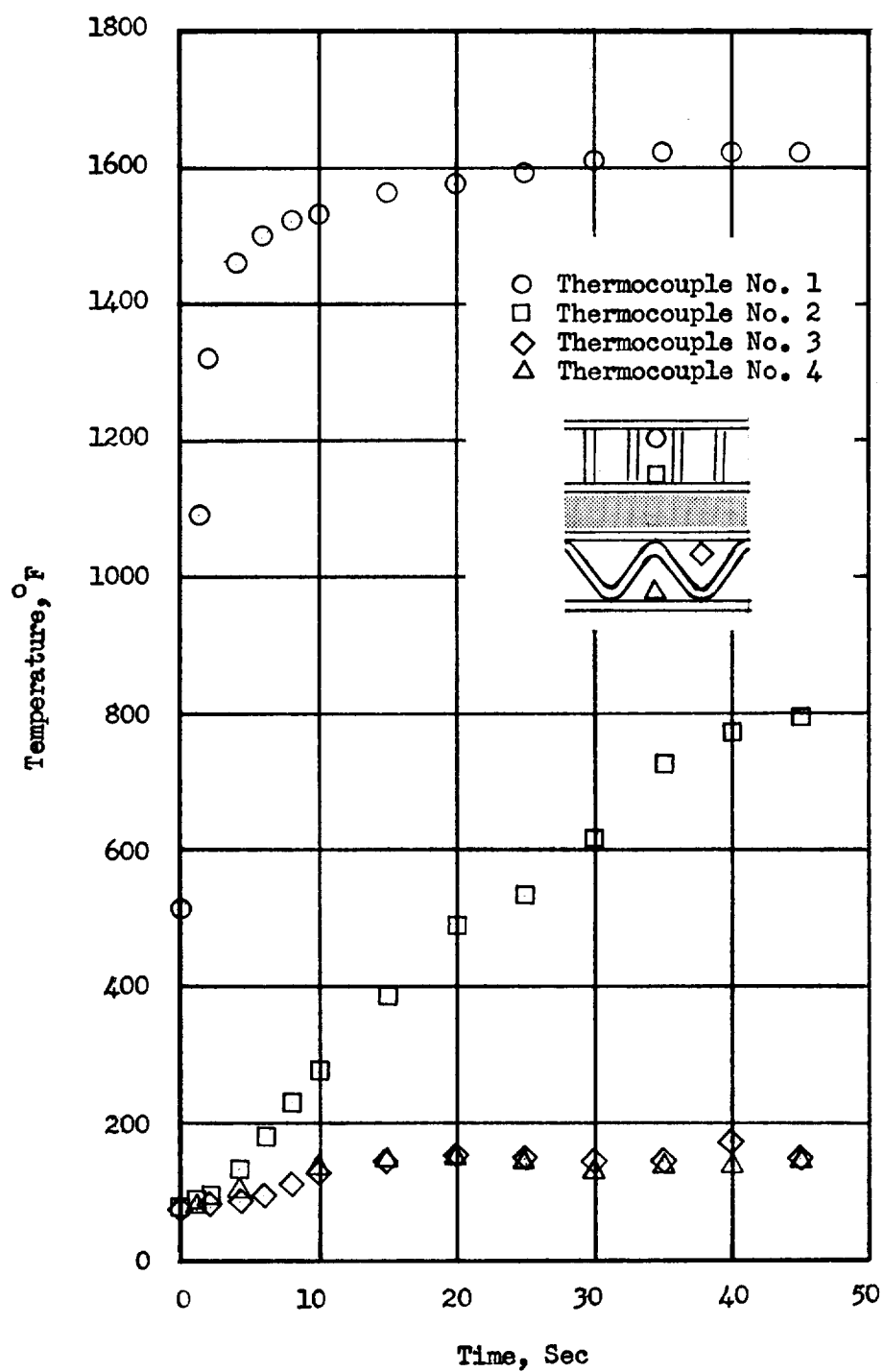
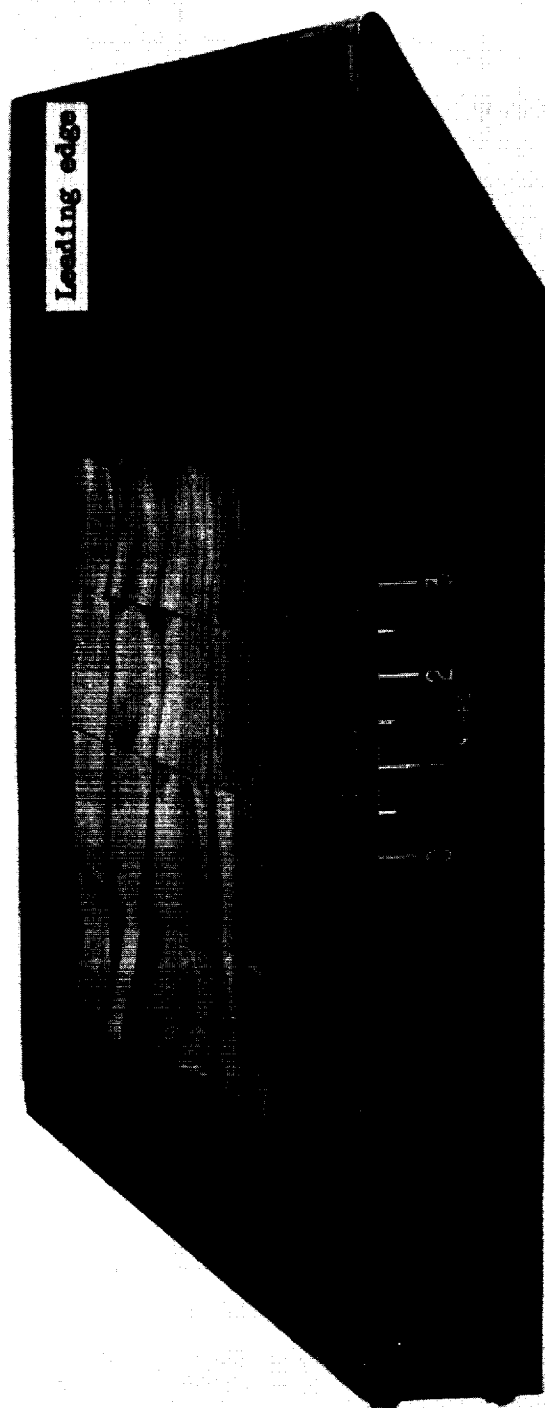


Figure 23.- Measured temperature-time histories for the insulated multipost heat shield. Ethylene-jet survival test.

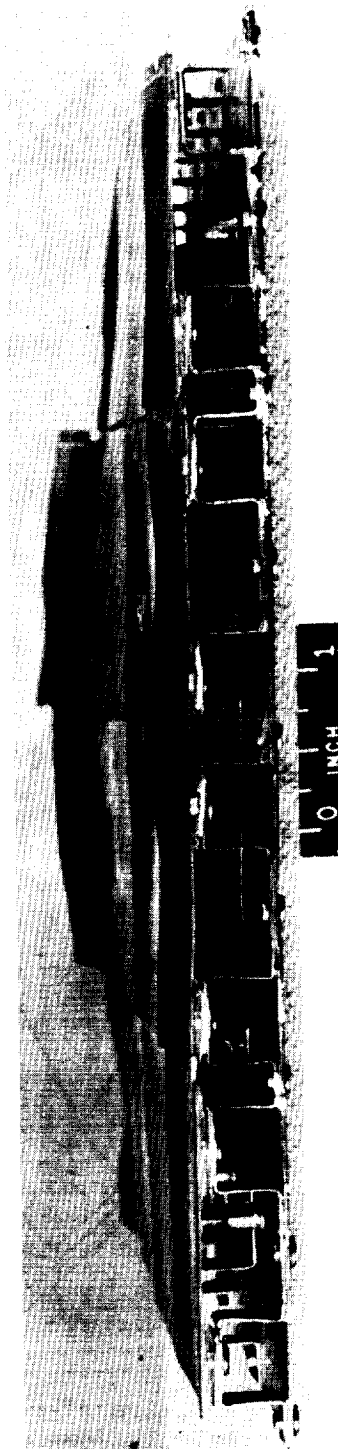


L-59-8707.1

Figure 26.- Photograph of stainless-steel-tile heat shield mounted in ethylene-jet support stand, after survival test.



(a) Perspective view.



(b) Leading-edge view.

L-61-2250
Figure 27.- Photograph of stainless-steel-tile heat shield after ethylene-jet survival tests.

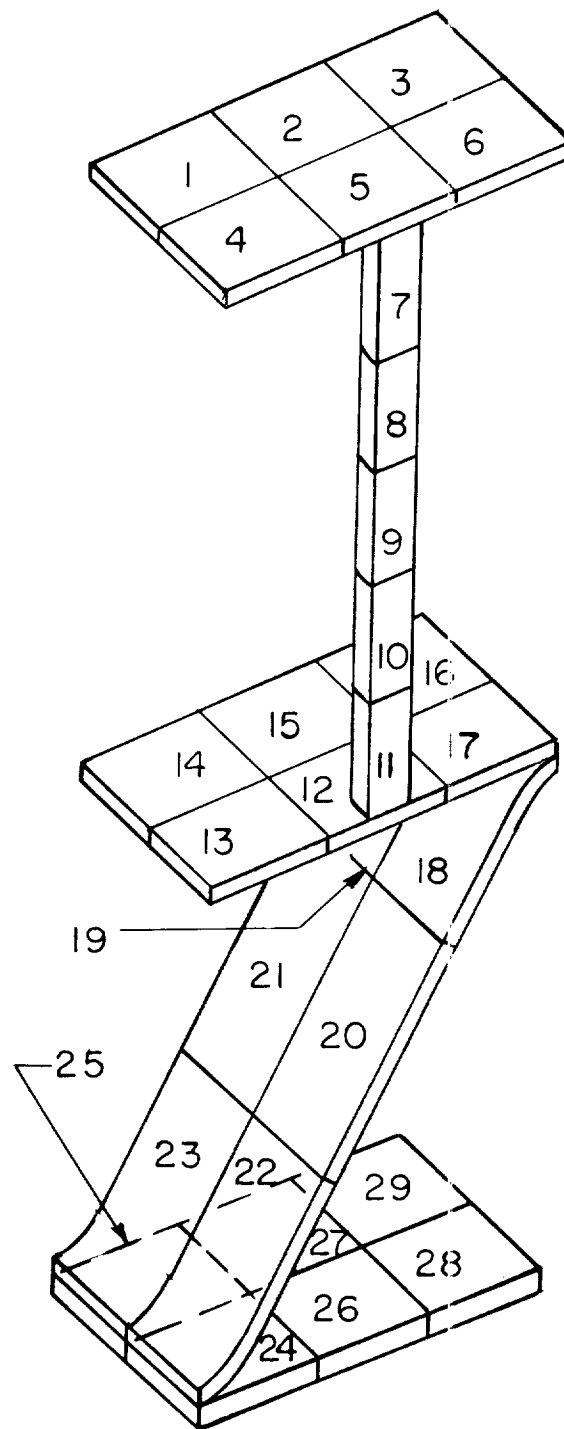


Figure 28.- Heat-transfer element used in temperature-distribution calculations for the multipost heat shield.